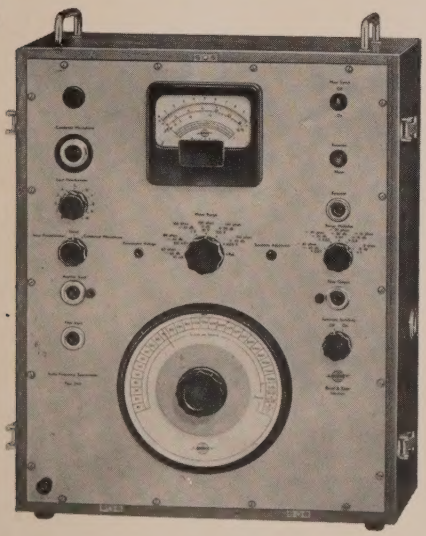
2109

INSTRUCTIONS AND APPLICATIONS

Audio Frequency Spectrometer Type 2109
Automatic Spectrum Recorder Type 2311



Spectrometer for both manual and automatic recording of electrical and acoustical spectrograms. Equipped with 27 fixed third-octave filters for the standardized main frequencies and low-noise amplifier. Connections for Condenser Microphone and Level Recorder.

- Beat frequency oscillators
- Low frequency oscillators
- Deviation test bridges
- Strain gauge apparatus
- Frequency measuring bridges
- Distortion measuring bridges
- Heterodyne voltmeters
- Audio frequency spectrometers
- Frequency analyzers
- Level recorders, a. c. and d. c.
- Automatic frequency response recorders
- Automatic A. F. spectographs
- Logarithmic potentiometers
- Noise level potentiometers
- Recording paper
- Polar diagram recorders
- Vacuum tube voltmeters
- Wide range vacuum tube voltmeters
- Diode voltmeters
- D. C. voltmeters
- Megohmmeters
- Microphone amplifiers
- Impact sound generators
- Acoustic standing wave apparatus
- Artificial ears
- Condenser microphones
- Microphone calibration apparatus
- Vibration pick-ups
- Integration networks
- Rotary selectors
- Universal selectors
- Frequency response tracers
- Conductivity meters
- Electronic counters
- Counting rate meters
- Impulse generators
- Portable dose rate meters
- Portable counting rate meters
- G. M. tubes & accessories

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AUDIO FREQUENCY SPECTROMETER

Type 2109

AUTOMATIC SPECTRUM RECORDER

Type 2311

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Description

The Spectrometer type 2109 is primarily designed as a universal tool for acoustical and electro-acoustical measurements, as for example working out vibration and noise spectrograms, measurements of sound pressures, noise and vibration levels, and as selective amplifier when measuring reverberation times.

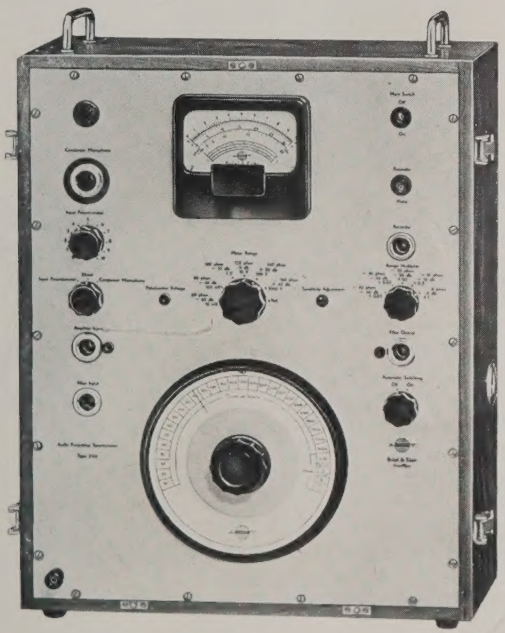


Fig. 1. Photo of the Audio Frequency Spectrometer type 2109.

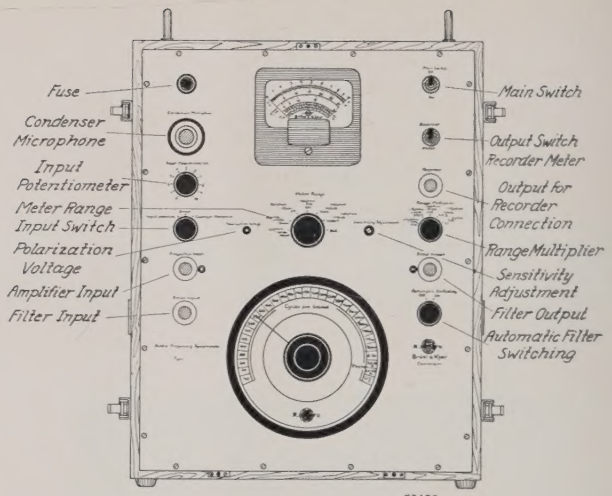


Fig. 2. Drawing of the Spectrometer 2109.

However, the instrument can be used with great advantage in pure electrical measurements, for example as indicator in bridge measurements and to analyze complex voltages.

The Spectrometer is designed to meet the demands drawn up by the "working committee" for the standardization of the measurements of sound transmission in the code of July 1949 and verified in May 1950.

The Spectrometer consists of a preamplifier, followed by 27 third-octave filters and 3 weighting networks. A switch after the filters can either automatically or manually select the 30 filters to the output amplifier, which drives either the meter or an external instrument, as for example the Level Recorder 2304.

The Condenser Microphone type 4111 can be connected to the Spectrometer.

All voltage supplies for the microphone with cathode-follower are obtained from the Spectrometer.

The connected tube voltmeter has dynamic qualities which are close to the demands for objective noise level meters.

The Spectrometer is designed for direct connection with our Level Recorder 2304 in order to make automatic recording of noise spectrograms.

Description of the Filters.

The 27 filters have mid-frequencies at $^1/_3$ octave distance. The frequencies are 40 - 50 - 63 - 80 - 100 - 125 - 160 - 200 - 250 - 315 - 400 - 500 - 630 - 800 - 1000 - 1250 - 1600 - 2000 - 2500 - 3150 - 4000 - 5000 - 6300 - 8000 - 10000 - 12500 - 16000 c/s. The figures are the so-called preferred numbers which are standar-

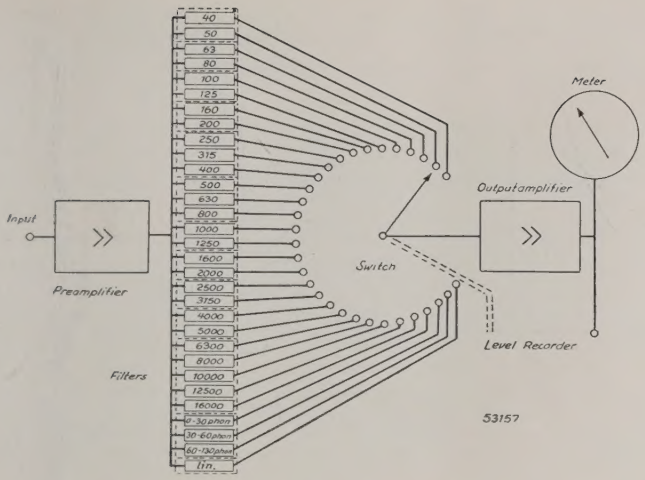


Fig. 3. Schematic diagram of the spectrometer 2109.

dized in most countries. The figures given here are the rounded-off values. The exact values are numbers whose logarithms are integral multiples of 0.1, i. e. whose mantissae are exactly 0.1, 0.2, 0.3 etc.

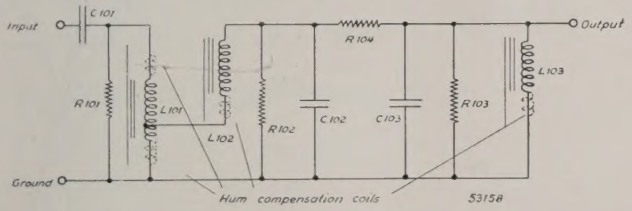


Fig. 4. Diagram of a third-octave filter unit.

The single filter consists of 3 resonant circuits coupled together as seen in figure 4, the two first having a quality factor Q approx. 10 and a coupling factor K =0.2, while the third has a Q of approx. 5 and is loosely coupled to the second with a coupling factor of order of magnitude K = 0.05.

The two first resonant circuits will give a two-topped frequency response as seen in fig. 5 left, while the third will give a single top which will raise the bottom between the two tops on the first curve, so that it gives a resultant curve as seen in fig. 5 right with a flat top and with very steep sides. Because the quality factor will vary somewhat with the frequency the two tops in fig. 5 left will not have the same height. The third resonant frequency must therefore be placed unsymmetrically to obtain a horizontal top. This top will

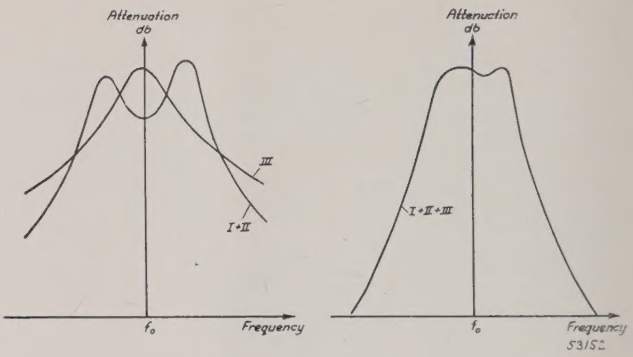


Fig. 5. Characteristics for filter unit.

therefore not be symmetrical but will have two humps, a broad one and a narrow one.

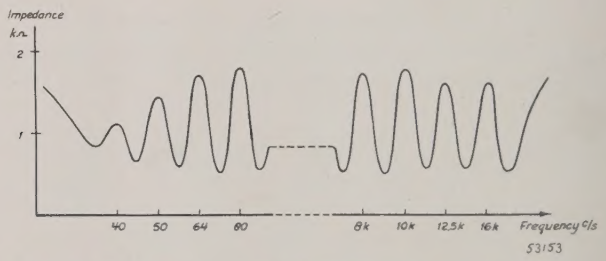


Fig. 6. Variation of input impedance of the filter section.

The input admittance curve of a single filter is a two-topped curve like that in fig. 5 left. The input impedance curve of all the filters together will therefore be a wave-curve varying between approx. 500 ohms and 2000 ohms, so that the impedance is high at the mid-frequencies and low at the band-limits. See fig. 6. The input voltage will therefore also vary up and down if the output impedance of the preamplifier is not made low. In the Spectrometer an output impedance of 25—30 ohms has been obtained by means of a permalloy autotransformer with winding ratio 10/1 and with a strong negative feedback. The input voltage on the filters will thus only vary approx ± 2 % up and down. If the filter is used alone without preamplifier, the output impedance of the measuring object should be low in relation to the 35 to 70 kohms between which the input impedance will vary, to obtain the best possible frequency response, both for the filters and for the linear position. It should also be remembered when the filter is used alone that the impedance put on

the filter output should be high. A resistance higher than 1—2 megohms parallel to a capacity lower than 20—30 pF is suitable. The filter can naturally be used even if these requirements are not satisfied, but the filter curves will be more or less spoiled.

The filters are adjusted so that the top of the frequency characteristic will have a peak to valley ratio less than 1 db, normally about 1/2 db, and so that the peaks will be between 0 and 1/2 db above the mean value of the input voltage (direct on the filters).

The top is "flat" within ± 1/2 db for about 1/4 octave. The attenuation at the band limits ± 1/6 octave from the middle is about 3 db, normally a little lower. See fig. 7. However, because of the great steepness of the filter curve at this point, one cannot expect the responses of two neighbouring filters to cross at about 3 db. For example, if the mid-frequencies of two neighbouring filters are displaced only 1 % in opposite directions, the cross-point will be about 1.7 db higher or lower, or if the width of the filter curves are altered 1 %, the cross-point will be about 0.2 db higher or lower.

The attenuation at ± 1/3 octave from the middle is adjusted to about 20—21

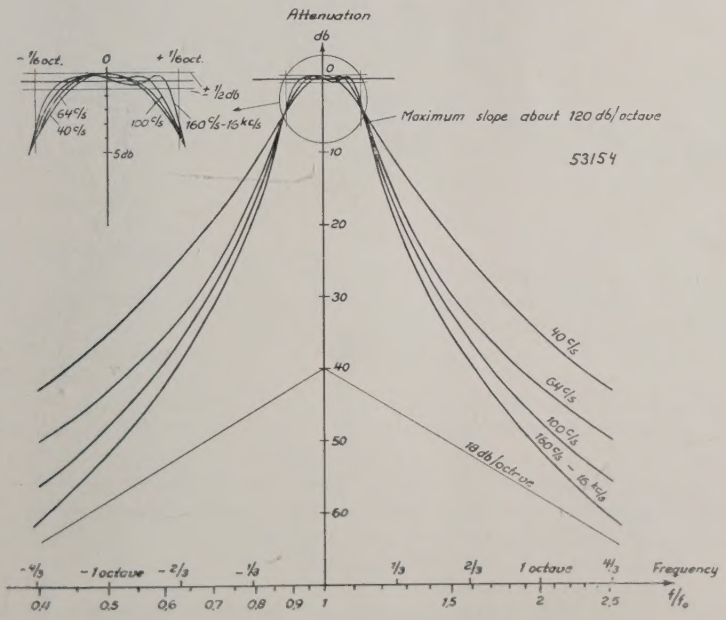


Fig. 7. Detailed filter characteristics.

db. The filter curve will then be as shown in fig. 7 with an attenuation of about 52 db at $\pm$ 1 octave.

However, it has been impossible to obtain sufficiently high quality factors for the coils at frequencies under 160 c/s, without lowering the stability or making the filters bigger and heavier. Thus the filter curves will be gradually worse for lower frequencies as seen in fig. 7 and 8. There will thus only be one top, and the "flat" part is only about $^1/_6$ octave, The attenuation is up to 4 db at the band limits, from 12 to 20 db at $\pm$ $^1/_3$ octave and from 35 to 50 db at 1 octave from the middle frequency.

As far as the lower frequencies are concerned it appears that magnetic fields from nearby mains transformers, electrical machinery and so on can induce quite considerable hum voltages in the coils even though these are placed in sealed pot-cores. It has therefore been necessary to place some coils outside the pot-cores and to connect these compensation coils as indicated in fig. 4, so that the hum voltages are reduced by a factor of 10 or more.

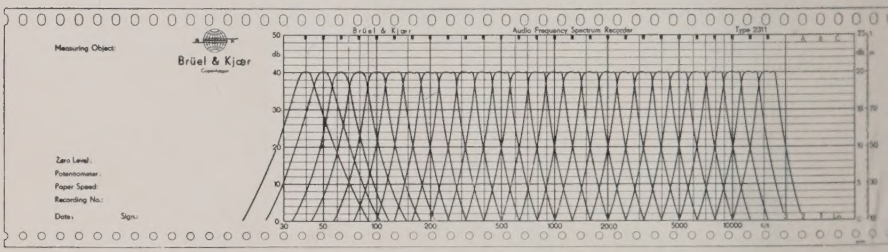


Fig. 8. The practical third-octave filter curves.

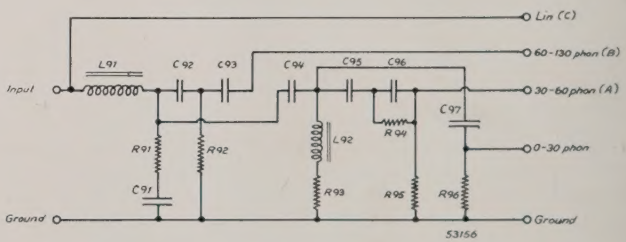


Fig. 9. Weighting networks for noise level measurements.

As regards the phon-filters, these are arranged as shown in fig. 9. The following curves are hereby obtained (see fig 10):

	c/s	30	60	125	250	500	1k	2k	4k	8k	20k
DIN 3	I	—52	—40	—27	—15	— 5					
DIN 2	ASA.A	—38	—27	—17	— 9	— 2	0	+1.5	+1.5	—8	—20
DIN 1	ASA.B	—19	—10	— 5	— 2	— 1					

Tolerance: $\pm$ 2 db except at 1 kc/s, where it is $\pm$ 1 db. These curves satisfy both the German DIN 5045 and the American ASA Z 24.3 standards for objective sound level meters.

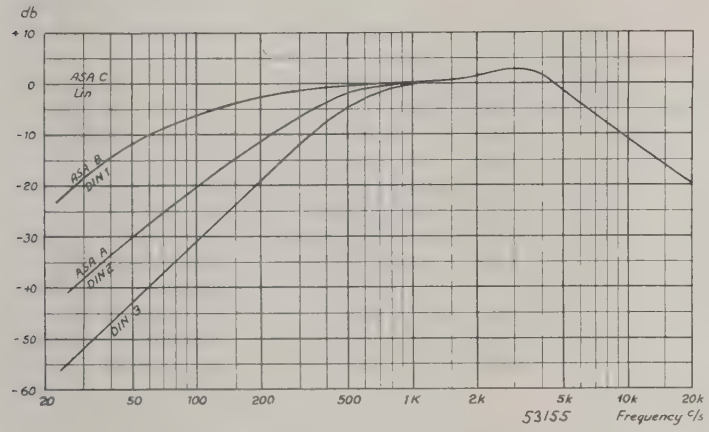


Fig. 10. The characteristics of the weighting networks.

If the filters are used alone without the pre-amplifier, care must be taken both that the impedance on "filter input" is sufficiently small and on "filter output" sufficiently large, and also that the input voltage is not too great. It should preferably not be over 10—20 volts, and definitely not over 50—60 volts, as thereby one will have saturation in the iron cores and also risk shorting-over in the coils.

Description of Amplifier.

The complete Audio Frequency Spectrometer type 2109 contains, besides the above described third octave filters with automatic switching, an input amplifier, an output amplifier, and the necessary rectifiers for operating these amplifiers as well as feeding the cathode-follower in a connected Condenser Microphone type 4111.

The purpose of the input amplifier is to adjust the signal voltage at the input terminals of the filter to approx. 1 volt. It consists of two stage amplifier, transformer coupled to the filter, and by means of a very powerful negative feed-back it has been possible to obtain a value of approx. 25 ohms for the impedance coupled to the filter, while at the same time the amplifier can supply approx. 1 volt to the filter with a maximum distortion factor of 1 part in 1000. The two amplifier tubes and corresponding coupling components are mounted on a special chassis, hung in rubber from the main chassis, and the tubes' filaments are fed with d. c. from a heater rectifier. In this way it has been possible to achieve a hum level on the grid of the input tube lower

than two microvolts, and there is no disturbance from microphony in the amplifier even when measuring only a few microvolts.

The amplifier has two input jacks. The one is seven-poled and corresponds to the plug on a Condenser Microphone type 4111, whose built-in cathode-follower gets the necessary filament and anode current from the audio frequency spectrometer. The other input jack corresponds to a 14 mm coaxial plug and can either be coupled direct to the amplifier's input circuit or via a volume control, used for relative measurements, as one then can arrange for full deflection for any reference voltage. Switching between these two alternatives as well as between the two input jacks is carried out with the help of a three-position switch, marked "Condenser Microphone", "Direct" for the direct input and "Input Potentiometer" for input via the volume control. The signal voltage is lead from the input switch to a voltage-divider with five steps of 20 db and with a total impedance of 2.2 megohms. This switch, marked "Meter Range" on the front plate, serves to adjust the apparatus' sensitivity, and the value for full deflection on the meter can be varied from 10mV to 1000 V. The switch has a further position marked "Ref." which serves to check the apparatus' sensitivity, a voltage stabilized with the help of a current regulator tube being applied to the grid of the input amplifier, in this position.

The output circuit of the input amplifier is coupled to the filter by means of an autotransformer with a ratio of 10 to 1. A powerful negative feed-back is lead to the cathode of the first amplifier tube from the transformer tapping which goes to the filter. In this way that very low generator impedance on the filter's input has been obtained which is necessary to ensure a satisfactorily flat top to the filter curves. If it is desired to use the filter without amplifiers, the input voltage is fed to the coaxial jack marked "Filter Input", and once more the voltage is led through the above mentioned transformer, so that with a generator impedance of 600 ohms or less one is sure of having that sufficiently low impedance on the filter. The impedance of the "Filter Input" input jack is approx. 50 kohms, when the amplifier is not in operation. Because of the transforming down, there is a damping of approx. 20 dbin the filter's range of operation, calculated between the coaxial jacks "Filter Input" and "Filter Output".

After the filter, whose characteristics are described above, there follows an amplifier which, in the same way as the input amplifier, has two steps and is supplied with negative feed back. In the feed-back circuit there is a potentiometer which can be adjusted with the aid of a screwdriver through a hole in the front plate marked "Sensitivity Adjustment", and which is used for adjusting the apparatus' sensitivity, the reference voltage being used as control. By means of a toggle swich the amplifier's output circuit can be connected either to the built-in rectifier instrument or to a coaxial jack marked "Recorder", serving for example either as connection to a head phones, oscillograph or level recorder. The output impedance on this coaxial jack is approx.

2 kohms, and a maximum voltage of approx. 30 V is available. The built-in meter has a full deflection for approx. 10 V. It is graduated 0—10 and 0—3.15, and also has a scale of 0 to 20 db. There is also a set of scales permitting a direct reading of absorption coefficients when using Standing Wave Apparatus type 4002.

Between the filter and the output amplifier there is inserted a voltage divider with 4 steps of 10 db. This switch is marked "Range Multiplier" on the front plate. As the meter, as mentioned, has a full deflection for 10 V, and the filter voltage is normally approx. 1 V, there is only need for an amplification of 10 times in the output amplifier. The total amplification of the output amplifier is 1000 times, therefore normally only $^1/_{100}$ of the voltage from the filter is used. When the "Range Multiplier" switch is in the position corresponding to this, indicated by "× 1", one has full deflection on the meter for that value given on the "Meter Range" switch. With this setting, voltages can be measured down to 3.15 mV, and with full deflection there is a ratio between signal- and noise voltage of approx. 60 db. If the signal voltage is lower than 3.15 mV, the amplification can be increased with the help of the "Range Multiplier" switch. The value of the full deflection on the meter is then the product of the two values read off on the "Meter Range" switch and the "Range Multiplier" switch, and the ratio between the signal- and noise-voltage decreases with just so many db as the amplification is increased with the "Range Multiplier" switch. By using the full amplification of the output amplifier, full deflection is obtained on the meter for 100 microvolts.

It will be seen from the above that the apparatus' amplification should be adjusted as high as possible with the "Meter Range" switch and as low as possible with the "Range Multiplier" switch, as in this way the best ratio is obtained between signal- and noise-voltage. However, care must be taken that the input amplifier is not overloaded. Before a frequency analysis is carried out, the filter switch is therefore set on the linear range, and the amplification adjusted as described. One will then have made sure that the voltage supplied by the input amplifier to the filter is at the most 1 V, and the input amplifier's distortion will thus be less than 1 part in 1000, corresponding to a ratio between signal voltage and disturbing voltages arising from distortion of more than 60 db. If a frequency analysis is thereafter desired, and even weak components of the spectrum have to be measured, the amplification is increased with the "Range Multiplier" switch, until a suitable deflection is obtained on the meter.

The power supply section of the apparatus contains three rectifiers. The one supplies filament current to the amplifier tubes, the next supplies filament current to the cathode-follower in a Condenser Microphone type 4111 if this is coupled on, while the third supplies anode voltage to the amplifier tubes and the cathode-follower, and the polarization voltage for the microphone cartridge. The anode voltage is stabilized with the aid of two glow tubes, and the polarization voltage to the microphone cartridge can be measured at a jack on the front plate of the apparatus marked "Polarization Voltage". The

apparatus can be operated from the a.c. supply with voltages of 115 - 127 - 150 or 220 V, and with 50 or 60 cycles per second. The consumption is approx. 30 watts. Switching for the different supply voltages is carried out by means of a voltage adjuster which is operated by means of a screwdriver through a hole in the back plate of the apparatus. An indicating plate coupled to the adjuster shows the supply voltage to which the apparatus is set. A fuse is set in the primary side of the supply transformer, placed in a fuse holder on the front plate of the apparatus. If it is desired to operate the apparatus from an accumulator, or from d.c. supplies, it is necessary to use a vibrator or rotary converter.

Instructions for Use.

After having made sure that the apparatus is adjusted to the appropriate power supply, it can be started with the aid of the switch marked "Main Switch". The lights on the meter and frequency scale will immediately go on, and after about two minutes the apparatus can be put in use.

The apparatus' sensitivity is checked with the help of the reference voltage, the frequency switch being set on the linear curve, "Meter Range" switch to "Ref.", "Range Multiplier" switch to "× 1", and the meter switch to "Meter". The meter should now show a deflection to the red mark on the scale, and possible deviations should be corrected with the help of the potentionemeter marked "Sensitivity Adjustment", adjusted with a screwdriver. This adjustment is carried out after waiting 20—30 seconds, so that the current regulator tube can have time to set itself to a stable current value.

Measuring of Electric Voltages.

The apparatus can be used as a linear tube voltmeter in the audio frequency range with a maximum sensitivity of 100 microvolts at full deflection. The voltage to be measured is lead to the single poled input jack, and the input switch set on "Direct". The input resistance is here 2.2 megohms and the input capacity approx. 20 pF. The frequency switch is adjusted to the linar curve, and the desired voltage range chosen with the help of the switch marked "Meter Range", if necessary in connection with "Range Multiplier", the "Range Multiplier" switch being set to the least possible sensitivity and "Meter Range" switch to the greatest possible sensitivity. This is in consideration of the ratio between signal and noise as previously described.

If a direct reading of voltage is desired, the meter switch is set to "Meter". The meter satisfies the dynamic requirements set out in DIN 5045, and is therefore relatively quick, so that it is also well suited for indicating relatively short lasting impulses. The meter measures the average value of the voltage but is calibrated in r.m.s. values for a sine wave voltage. The output amplifier can give a voltage which is 10 db greater than corresponds to full deflection for the meter. In this way a correct addition has also been assured for voltages of an impulse character.

If it is desired to record the voltages measured on a level recorder, for example type 2304, this should be coupled to the output jack marked "Recorder". With full deflection on the meter a voltage of 10 V is provided here, and as mentioned the amplifier is able to give a further 10 db higher voltage, i. e. approx. 30 V. The output impedance is approx. 2 kohms, and as a consequence is small in comparison with the level recorder's approx. 25 koms.

Analysis of Audio-Frequency Voltages.

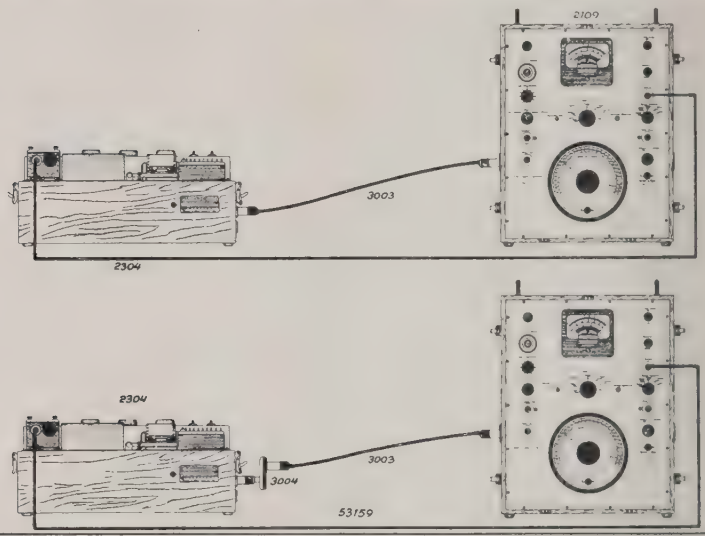
Before one carries out a voltage analysis, one makes sure that the voltage does not overload the apparatus' amplifier. Therefore one sets the frequency switch to the linear curve and measures the voltage as just described. One then sets the frequency switch to the desired frequency band, and reads the corresponding voltage on the meter. If one wishes to read voltages which are so small that they give no obvious deflection on the meter, the amplification can be increased with the help of the switch marked "Range Multiplier". On the other hand the amplification should not be increased by means of the switch marked "Meter Range", as in this way the input amplifier is overloaded and undesirable distortion- and combination-tones are produced.

The audio frequency spectrogram can be recorded on paper types 3601-2-3, with the assistance of a level recorder of type 2304 or 2334. The recorder's gear case is then connected to the spectrometer's automatic switch by means of a flexible shaft, and the recorder's potentiometer coupled to the jack marked "Recorder". The switch "Meter Recorder" is turned to the recorder position. A 50 db potentiometer is preferably used, and the volume control in the potentiometer so adjusted that full deflection on the spectrometer's meter corresponds to approx. 40 db. The knob marked "Switching" is set to "On", and when the motor in the level recorder draws the paper forward on the recorder, the automatic switch will at the same time carry out the switching to the various filters.

For acoustic analysis Condenser Microphone type 4111 is used. It can be connected to the seven-poled screened jack on the spectrometer's front plate, either by inserting the microphone's seven poled plug direct in the jack, or by using an intermediate unit in the form of floor stand type 4112, extension cable type 4114 or extension rod type 4115, supported by 4116. The input switch is then set to "Condenser Microphone", and an adjustment of the amplifier carried out, as will be described on p. 31 under "noise measurement", after which sound pressure or phon values can be read off direct on the spectrometer's scale. The procedure is thereafter the same as with electrical analysis, and the results can be recorded in the form of a spectrogram by means of the level recorder. At the same time the phon value of the noise can be measured with the help of the three built-in phon filters in the apparatus, these satisfying the standards in DIN 5045. If it is wished to carry out measurements in accordance with the American standards ASA Z 24.3, the three positions on the switch marked A, B and C should be used.

Coupling to Level Recorder 2304.

In order to make full use of the advantage of the spectrometer, which is to have all 30 filters coupled in parallel directly following the pre-amplifier,



Length of Recording Paper in centimeter for one Revolution on 2109 main dial										
Wheel No.	Paper speed in mm/sec									
	100	30	10	3	1	0.3	0.1	0.03	0.01	0.003
A 75 r/m	400	120	40	12	4	1.2	0.4	0,12		
	240	72	24	7,2	2.4	0.72	0.24	0,072		
B 22,5 r/m	1333 1/3	400	133 1/3	40	13 1/3	4	1 1/3	0.4	1/3	
	800	240	80	24	8	2.4	0,8	0,24	0.08	
C 7,5 r/m		1200	400	120	40	12	4	1.2	0.4	0,12
		720	240	72	24	7.2	2.4	0,72	0,24	0,072
D 2,25 r/m			1333 1/3	400	133 1/3	40	13 1/3	4	1 1/3	0.4
			800	240	80	24	8	2.4	0.8	0,24
E 0,75 r/m				1200	400	120	40	12	4	1,2
				720	240	72	24	7,2	2.4	0,72
F 0,225 r/m					1333 1/3	400	133 1/3	40	13 1/3	4
					800	240	80	24	8	2.4
G 4,5 r/h						1200	400	120	40	12
						720	240	72	24	7,2
H 1,35 r/h							1333 1/3	400	133 1/3	40
							800	240	80	24
I 0,45 r/h								1200	400	120
								720	240	72

Fig. 11. Connection of spectrometer 2109 to Level Recorder 2304 without and with Speed Multiplier 3004. Table of the lenghts of recordings at different paper speeds and wheel positions.

and switch the filters' output, the spectrometer should be coupled together with a Level Recorder, so that the output from any one filter can be recorded in a fraction of a second.

Spectrometer 2109 is constructed for very convenient coupling to High Speed Level Recorder 2304. As is shown in the drawing of fig. 11 a flexible shaft type 3003 is attached either to the left hand or right hand side of the spectrometer, the other end of the shaft being attached to the Level Recorder's gear-box. It is indifferent which of the two terminals on the gear-box is used. The speed with which it is desired to traverse the spectrograms is adjusted with the help of the shift pinion in the gear-box. To shift the pinion the small door on the front of the Level Recorder is opened and the pinion moved with the aid of a thin screwdriver or knife blade, and once the pinion has engaged in the proper position it is automatically locked there with a snap lock. By choosing various paper speeds on the recorder it is possible to obtain a wide range of frequency scales varying from some few millimetres to several metres interval between the frequencies of 40 and 16000 c/s. Paper with pre-printed frequency scales as indicated in fig. 14 is available. This paper corresponds very closely in quality and printing with the recording paper used in the Automatic Frequency Response Recorder type 2314. Similarly, one complete revolution of the main scale on the Spectrometer type 2109 corresponds to 240 mm on the paper.

In order to get the printing on the paper to fit, the Speed Multiplier type 3004 must be inserted between the Level Recorder and the Spectrometer, as indicated in fig. 11.

Synchronisation between the frequencies indicated on the recording paper and the filter frequencies on 2109 is most easily carried out with the motor on the recorder stopped. All the levers on the gear-box are disengaged, and the recording paper shifted by means of the small finger wheel to the right of the gear-box, so that the writing point lies for example at 40 c/s. Then the main scale on the spectrometer is turned to the 40 c/s filter. The lever which sets the paperaxle in operation is then connected, at the correct speed. It is then only necessary to start the motor on the recorder, and the paper and Spectrometer will run in synchronism. It is, however, not always the case that the middle portion of the filter corresponds exactly to the points on the paper, so it is therefore necessary in that case to carry out a fine adjustment by simply turning the Speed Multiplier back or forward a little.

When the shift pinion in the gear-box is in the position of maximum speed, that is, position A, the paper speed should be 10 mm per sec. When the pinion is in position B, the speed is 3 mm per sec., in position C 1 mm per sec., and so on. This also follows from the table in fig.11, which gives the length of the main dial on 2109 for different paper speeds and positions of the shift pinion.

The upper figures in each wheel-column A, B, C etc. are effective without the Speed Multiplier, and the figures below, with the Speed Multiplier. The figures in frames indicate the positions in which the pre-printed paper is effective.

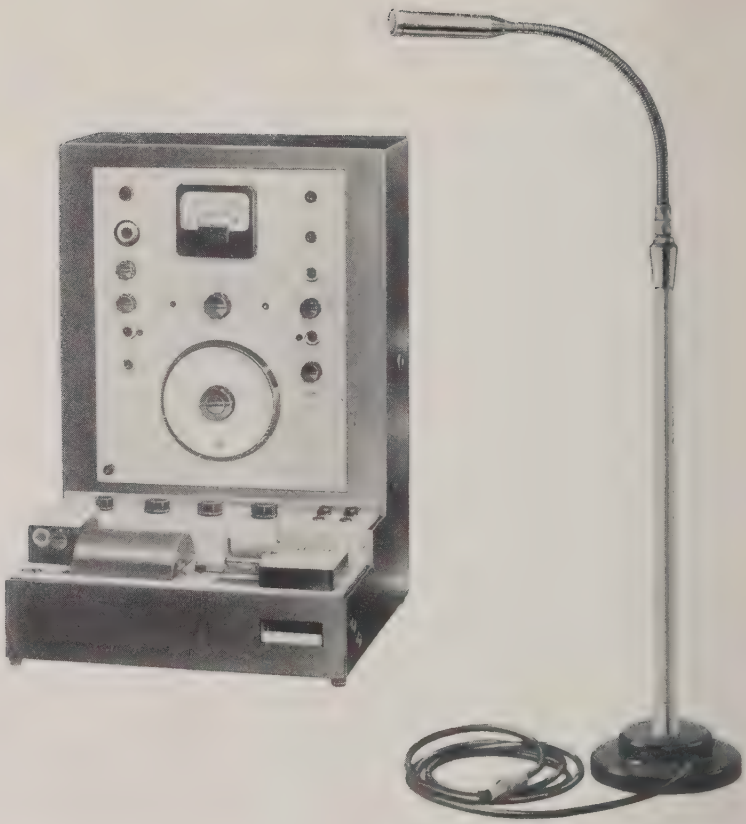


Fig. 12. Photo of Audio Frequency Spectrum Recorder 2311 and Microphone Stand 4112.

Combination 2311.

This apparatus consists of the Audio Frequency Spectrometer type 2109 and the High Speed Level Recorder type 2304 mounted together in a 19" rack. The Level Recorder and the Spectrometer are connected by means of a chain drive, making possible the automatic recording of the sound analysis and acoustic noise, or a complex voltage. For this set up Microphone 4111 in Stand 4112 is as a rule used, coupled direct to the Spectrometer with the 10 metre long cable. The above mentioned pre-printed paper is here used without inserting the Speed Multiplier mentioned, because the chain drive is constructed to give the proper speed converting. Regarding the use of the Level Recorder, refer

ence can be made to this instrument's operating instructions. Adjustment of the gear-box shift pinion and paper speeds follows from the table in fig. 11, where the figures in the lowest row of the wheel-columns are effective.

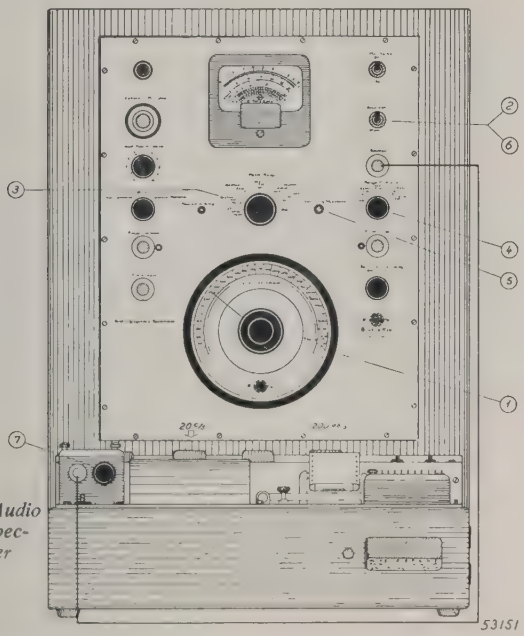


Fig. 13

Drawing of Audio Frequency Spectrum Recorder 2311.

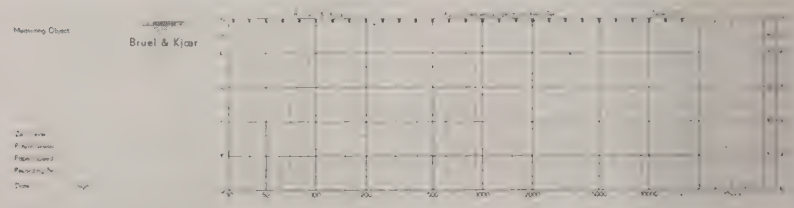
Fig. 12 shows a photograph of the apparatus with associated Condenser Microphone, and in fig. 13 a drawing of the Audio Frequency Spectrum Recorder is given.

In this drawing the different numbers indicate the procedure how to adjust the apparatus in order to give the recording an absolute reference value.

1) Set Main Scale on 2109 on linear.
2) Set Meter Switch on Meter.
3) Set Main Attenuator on Ref.
4) Set Multiplier on 0.3.
5) Adjust Sensitivity Adjustment to Full Scale Deflection.
   Now the inputsignal has such a value as to give 10 V on the output.
6) Set Meter Switch in position Meter.
7) Set on Level Recorder 2304 Lower Limiting Frequency on 20 c/s and Writing Speed about 200 db/s.
8) The volume control on the 50 db potentiometer on the Level Recorder should be screwed down to about 1/10 until the stylus stands on the 40 db line. In this way the 40 db line will correspond to full scale deflection in

any combination of the positions of the switches "Meter Range" and "Range Multiplier". The 40 db line is therefore chosen to allow an overshoot of 10 db which is possible to handle for the output stage of the Spectrometer.

The recording paper with printed frequency diagram is supplied in three different paper types, one of which is shown in fig. 14. Type 3601 is white paper intended for ink recording. Type 3602 is black paper coated with white wax, in which the record is scratched with the sapphire stylus. Type 3603 is transparent paper coated with red wax. The curves show up in this case as transparent on a red background. This paper is specially suited for blue prints, and with an ordinary oxalid paper or photostatic copy paper gives a very contrasty reproduction.



Type 3601.

Fig. 14. One of the three different types of recording paper for 2311 with pre-printed frequency diagram.

Transparent Recording Paper Type 3603.

The transparent recording paper type 3603 is placed on the recorder 2304 or on the recording section in 2311 as with any other recording paper. The diagram is printed in black on top of the red wax layer, and it is adjusted in the normal manner in synchronism with the scale pointer on 2109, after which the spectrograms can be recorded. The curves scratched by the sapphire point will be transparent, as both the red wax and the black printing will be removed by the sapphire stylus. When one wishes to make copies of the curves, either on photostatic paper or oxalide paper, only the scratched curves will appear on the copy, the original being transparent only here. Thus the frequency diagram itself will not appear on the copy. If it is desired to have the frequency diagram also printed on the copy, a double copying must be carried out, using a special diagram-negative, shown in fig. 15, and consisting of a black film on which the frequency diagram appears as transparent lines. The procedure is as follows: first, the recording paper strip to be copied is fastened to a board or table with scotch tape in such a way that the whole strip can be turned to one side and a piece of copying paper inserted underneath, without shifting the position of the strip. Before doing this, the film

with the transparent lines is placed on the recording paper strip in such a way that the printing on the strip coincides precisely with the transparent lines on the film. The film is then also fixed to the board with a hinge of scotch tape. The photostat paper is then placed under the recording paper strip alone, and the curve illuminated. Then, without disturbing the photostat paper, the recording paper strip is turned to one side, the black film in turn laid on the photostat paper, and the frequency diagram copied. By illuminating the curve somewhat longer than the black film with the frequency diagram, it is possible to enhance the former so that it stands out in contrast to the lines in the latter. All the diagrams shown in this book are made in the manner here described.

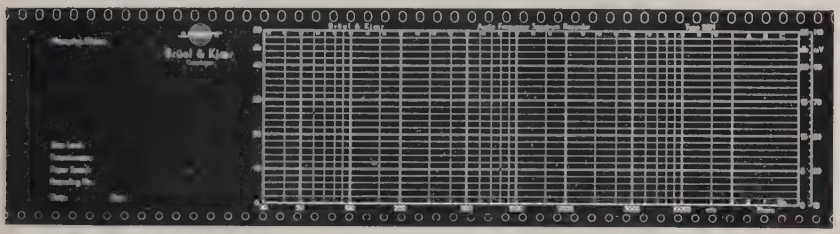


Fig. 15. Black film with transparent frequency diagram, for copying transparent recording paper type 3603.

Applications.

Audio Frequency Spectrometer 2109 as Bridge Indicator.

When making bridge measurements in the audio frequency range it is a great advantage to have a reliable and selective instrument in the bridge network. The only requirement the bridge must satisfy is that one diagonal point can be grounded as shown in fig. 16. This requires that the bridge be supplied from a Beat Frequency Oscillator via a well-shielded transformer, the signal generator often being grounded at one terminal. When making bridge measurements the spectrometer's selectivity and great sensitivity can both be made use of. Further, the decibel scale incorporated in the instrument's meter will often be of use, if it is desired to measure the goodness of the different components placed in the bridge. A further advantage with the spectrometer is that the selectivity curve is relatively flat over a 1/3 octave band, so that it is thus possible to vary the Beat Frequency Oscillator frequency to some extent without having to adjust the spectrometer setting, while the attenuation of possible hum components and higher harmonics will still be extremely powerful. As previously mentioned, electrical voltages can be measured by setting the main switch to "Lin". The voltage can then be read directly on the instrument's volts scale in connection with the two attenuator positions, which together indicate the full scale deflection. Here the instrument is completely protected against overloading. The voltages can also be read off in db with reference to 1 volt. The db scale on the instrument is read off, and to this value is simply added the db-indication on "voltage range" and "range multiplier". For voltages below approx. 10 microvolts noise from the input tube and grid leak will cause trouble on the linear frequency characteristic, so that it is necessary with these small voltages to use selective amplification.

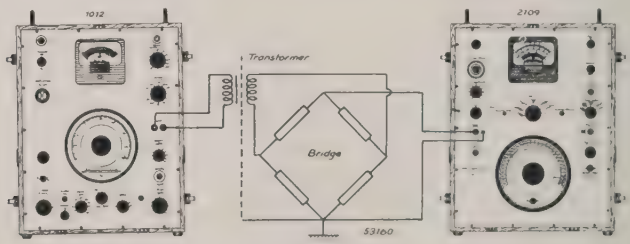


Fig. 16. The Spectrometer used as bridge indicator.

The Audio Frequency Spectrometer used as Analyzer.

With the Spectrometer type 2109 it is not possible to carry out so fine frequency analyses as with a continuously variable analyzer such as type 2105.

On the other hand the very powerful damping of frequencies outside the pass band is particularly valuable. The frequencies of the different partials are often known, in which case an exact analysis can be carried out by measuring the voltages. An example is shown in fig. 17, the analysis of the voltage in a power line. The fundamental here is 50 c/s, and all the harmonics must be whole multiples of this frequency. In this way it is possible, as shown, to record a spectrogram in which the mutual magnitudes of the harmonics are precisely given. If the distance between the harmonics is of the same order of magnitude as the bandwidth of the spectrometer, is is naturally impossible to separate the different harmonics from each other. For example, it is difficult to discriminate the 6th and 7th harmonics from each other.

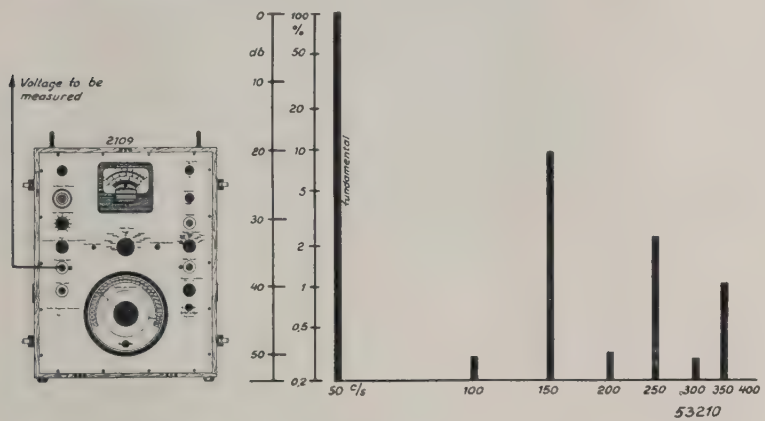


Fig. 17. Example of analysis of a power line.

If it is required to analyze a fundamental and a small number of harmonics, it may be convenient to have the harmonics measured as a percentage of the amplitude of the fundamental. For this purpose the instrument should first be tuned to the fundamental frequency, and a maximum deflection produced on the meter, the input switch being set to "volume control", and the amount of deflection adjusted with the volume control. The instrument should now be switched to the different harmonics, whereupon the percentages can be read on the meter scale. The ranges of 0—30 %, and 0—10 % are obtained by increasing the amplification by 10 and 20 db with the "range multiplier" switch.

Distortion Measurements on Nearly Pure Tones.

If it is wished to measure distortion-factors and furthermore analyze the lower harmonics of nearly pure a. c. voltages such as the output from a high-quality oscillator, it may be that the spectrometer's selectivity will not go as

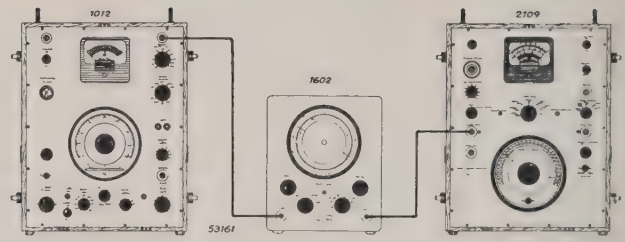


Fig. 18. Distortion measurements of nearly pure tones by using the Blocking Network type 1602.

far as this. The spectrometer can then be used in connection with the Blocking Network type 1602, as shown in fig. 18.

The Blocking Network 1602 is adjusted to damp a single frequency very strongly, while allowing all the other frequencies to pass through the filter. Measurements are made by first setting filter 1602 to its linear range, then adjusting the spectrometer's sensitivity so as to give full deflection for the frequency in question. The spectrometer can then either be switched to its linear range, or selectively tuned to the fundamental frequency. The filter is then tuned so that the deflection on the analyzer becomes minimum, i. e. the basic frequency is completely damped out. Analysis of the harmonics can then be undertaken in the normal way, and in practice it is possible to measure distortion components right down to 0.01 %. In this case even the "meter range" switch can be used to increase the amplification. To obtain the correct amplitude relation with frequencies which lie below the fundamental frequency, for example various hum components, filter 1602's frequency characteristic must be used for correction. The correction of frequencies which lie above the fundamental frequency is not necessary. The total distortion can be calculated by adding the effect of the various components, but it can also be obtained direct as a minimum deflection on the spectrometer when set to the linear response after the filter has been adjusted to give minimum.

Vibration Measurements and Analyses.

Using our Vibration Pick-up 4303 or 4304 and our Integration Network 1605 or 1604 vibrations in buildings, machinery, ships etc. can be measured and analyzed. Acceleration-, velocity- and deflection amplitudes can be measured directly in C. G. S. units. The Network 1605 or 1604 can be switched for connecting three different vibration pick-ups. Another knob switches the Network for acceleration-, velocity- and deflection-amplitude measurements. The vibration pick-ups are piezo-electric pick-ups with a sensitivity for type 4303 of about 80 mV per 1000 cm sec^2 and for type 4304 about 20 mV 1000 cm sec^2. The pick-up type 4303 can be used up to 1600 c/s and has a basic resonance frequency at about 2200 c/s. At this frequency the sensitivity is increased

Fig. 19. Photo of Vibration Pick-up 4304 and Integration Network 1604.

approx. 15 db. Type 4304 can be used up to 5000 c/s and has resonance at 6500—7000 c/s. The lower frequency limit is lower than that of the spectrometer.

When measuring velocity-amplitudes instead of acceleration-amplitudes the filter's lowest control is placed in the middle position "v", in which case the acceleration is integrated with respect to time, so that the filter's output voltage becomes proportional to the velocity of the vibration. It is only necessary to read the output voltage in mV on the Spectrometer and multiply by the conversion factor shown on the filter. The velocity-amplitude is then immediately given in cm sec. In position "a" deflection-amplitudes are obtained, as the integration is carried out twice. With each integration a certain degree of accuracy is lost, and is is therefore recommended that work be carried out mainly with acceleration and velocity amplitudes, and that deflection-amplitudes be seldom used. In any case there is seldom use for deflection-amplitudes, as the forces to which various objects are subjected are directly proportional to the acceleration, and as can be seen from fig. 20, the "irritation effects" which vibrations have on people are in the main proportional to their velocity-amplitudes.

The effect of vibration on the human organism is shown in fig. 20, where

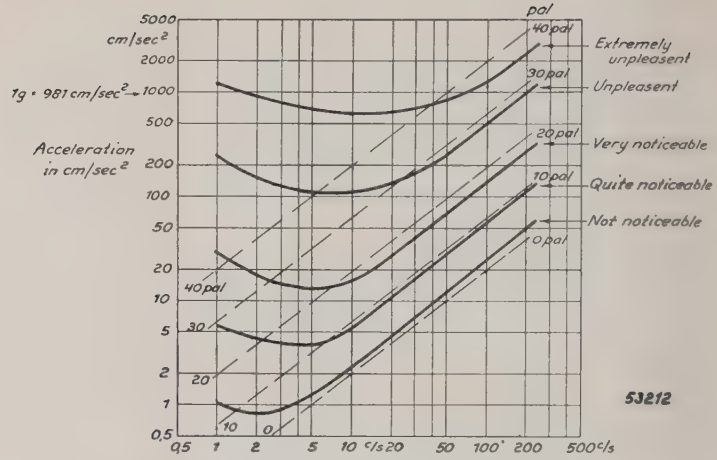


Fig. 20. The "irritation effects" of vibrations on the human organism.

the curves set out show the relationship between the acceleration and frequency of vibrations and the degree to which they are noticed by the organism. The curves are an average of results of measurements on both sitting and standing persons, in which only sinusoidal vibrations were used.

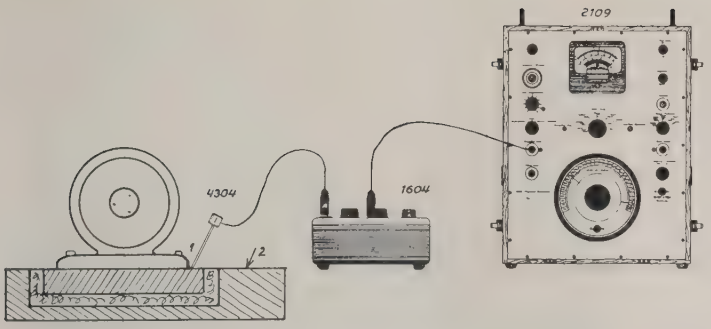
It will be noted that with low frequencies the human judgment of the strength of vibrations is mainly dependent on and proportional to their velocity. This has given rise to the suggestion of a unit, the "pal", as a measure of the strength of vibrations. 0 pal corresponds to that vibration velocity which a man can just experience. "pal" units are defined as:—

$$\text{Strength of vibration in pals} = 20 \log \left(\frac{u}{u_0}\right)$$

Where u is the effective value of the vibration's velocity-amplitude and u_0 is a reference level $u_0 = 0.0312$ cm/sec.

The "pal" scale thus corresponds to the normal decibel scale with a reference value of 0.0312 cm/sec. As can be seen from fig. 20 the "pal" scale corresponds rather poorly with the human power of perception for frequencies lower than 20—50 c/s.

Fig. 21 shows a typical example of a set-up with vibration pick-up 4304, integration network 1604 and spectrometer 2109, for the measurement of vibration amplitudes in a motor foundation. Below the figure are the results for measurements on the foundation itself at the position marked 1 on the figure, and measurements at the same frequencies, but at a point marked 2, outside the vibration-isolated foundation. The measurements are in this case read off directly from the spectrometer's instrument scale, even though the results are recorded on the recording paper type 3601. Fig. 22 shows how



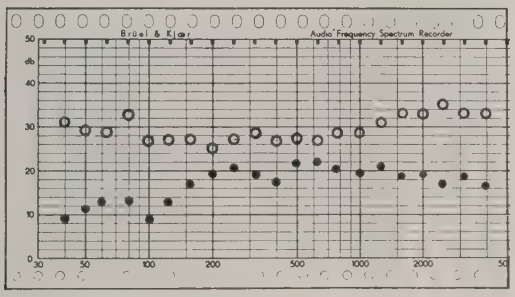


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Fig. 21. Vibration measurements for a motor foundation.

a similar measurement of accelerations is carried out on a motor foundation supported on vibration absorbers. The measurements are carried out with the Audio Frequency Spectrum Recorder type 2311. In this case no integration network has been interposed, and the acceleration of the vibration amplitude is recorded direct. At the bottom of the figure is the record of the acceleration amplitude for the motor foundation itself at a point marked 1 and outside the foundation at a point marked 2. From the difference between the curves the insulation in db as a function of frequency can be immediately estimated.

Measurements of Sound Pressure with Condenser Microphone Type 4111.

The Condenser Microphone type 4111 can be connected to the Spectrometer type 2109 or fastened to the Stand type 4112 which again is connected to the Spectrometer, as seen in the photograph in fig. 23. The microphone mounted on Floor Stand type 4112 is shown to the left. This stand has a 10 metre long cable, and if necessary this can be extended with several lengths of Extension Cable type 4114. In the middle is shown the method of mounting with Extension Rod type 4115, which is attached to the top of the front plate of the

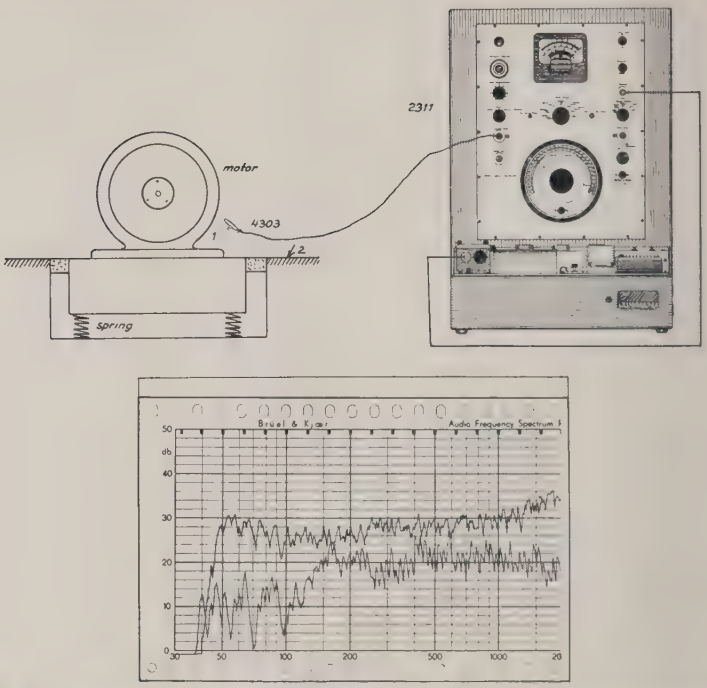

Fig. 22. Automatic recording of vibrations in and around a vibration-damped motor foundation.

spectrometer with a special fitting type 4116. This method of attachment of the microphone is particularly practical for mobile measurements and noise analyses. To the right the microphone is seen connected via Extension Cable type 4114, which is normally 10 metres long, and as mentioned several lengths can be coupled together. Both microphone and accessories should be handled carefully, and they should be assembled and mounted without using extreme force. When the condenser microphone is not in use, it should be kept together with the Extension Rod in its case. The special protective cap should be placed on all the 7-pin plugs when not in use. Particular care should be shown the protective screen which sits over the diagram. This grid will not stand too violent shocks, and if for example the microphone is dropped on the floor with the screen down, there is a risk of destroying the diaphragm. For further details concerning the condenser microphone see the instruction book for this equipment. At the back of the microphone instruction book will be found an individual calibration for the particular microphone in question.

Fig. 23. Photo of the Condenser Microphone Type 4111 connected to the Spectrometer. Left: Floor Stand Type 4112. Middle: Extension Rod Type 4115. Right: Extension Cable 4114.

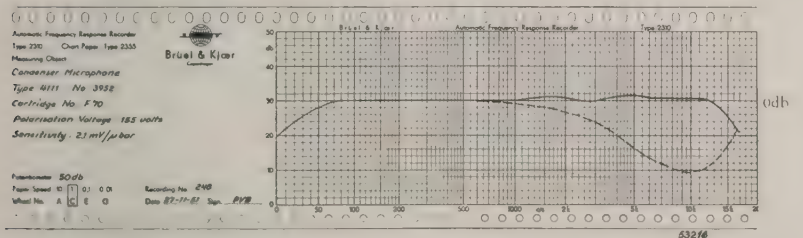

Fig. 24. Frequency response and absolute sensitivity for Condenser Microphone Type 411.

Fig. 24 shows such a curve, showing the freefield calibration of the condenser microphone. Both the condenser microphone's serial number and the cartridge's serial number are given on the curve. The sensitivity is expressed in mV per μbar for a definite specified polarisation voltage. The sensitivity given corresponds to the output voltage after the built-in cathode follower in

the microphone. If the microphone is attached to a spectrometer whose polarisation is different to that with which the microphone has been measured, a correction for the difference in polarisation voltage must be made, the sensitivity being directly proportional to the polarisation voltage. To measure the polarisation voltage given by the spectrometer, an ordinary sensitive voltmeter (current consumption not over 50 μA) can be used, connected between the jack marked "Polarisation Voltage" and ground.

When the Spectrometer's voltage sensitivity is adjusted as previously described, as precisely as possible, the measurements can begin. If pure tones are being measured, for example, those from a loud-speker driven by a beat-frequency oscillator, the linear frequency characteristic can be used, and the voltage indicated as a function of the frequency read off and noted. If the sound pressure being measured is very small, so that undesired noise disturbes the measurement, it is recommended that the selective ranges on the Spectrometer be used. When the measured results are finally available in the form of voltages, measured in mV, these should be converted by means of the microphone's sensitivity curve to sound pressures in μbars or in db above 1 μbar. (1 μbar = 1 dyn/cm^2). As the Spectrometer scale is graduated to show the r. m. s. values of the voltages, the sound pressures obtained are also r. m. s.

To simplify the conversion from voltage to sound pressure *the following table should be filled out* with the multiplication factors for the various standard frequencies. The multiplication factors are the reciprocal of the sensitivity and are given in μbar/mV.

Standard Frequency c/s	Multiplication Factor μbar/mV	Standard Frequency c/s	Multiplication Factor μbar/mV
		630	
		800	
		1000	
40		1250	
50		1600	
63		2000	
80		2500	
100		3150	
125		4000	
160		5000	
200		6300	
250		8000	
315		10000	
400		12500	
500		16000	

This table is effective for Spectrometer No with Condenser Microphone type 4111 No . 1. Check Spectrometer's voltage sensitivity. 2. Measure with the sound waves stricking the microphone diaphragm normally. 3. Multiply the voltages read in mV by the above multiplication factors. The sound pressure will then be obtained in μbar = dyn/cm^2.

Spectrograms.

The Spectrometer's most important use is the recording of acoustic spectrograms of different sounds in conjunction with Condenser Microphone 4111. With Condenser Microphone 4111 and the Audio Frequency Spectrometer alone, the sound pressure in each band must be read off on the Spectrometer's instrument. These values as read off must then be recorded in a frequency spectrum so as to facilitate a comprehensive picture. With the combination of Microphone 4111 and Audio Frequency Spectrum Recorder 2311, the spectrograms are directly recorded, and on the following figures a series of characteristic examples are shown.

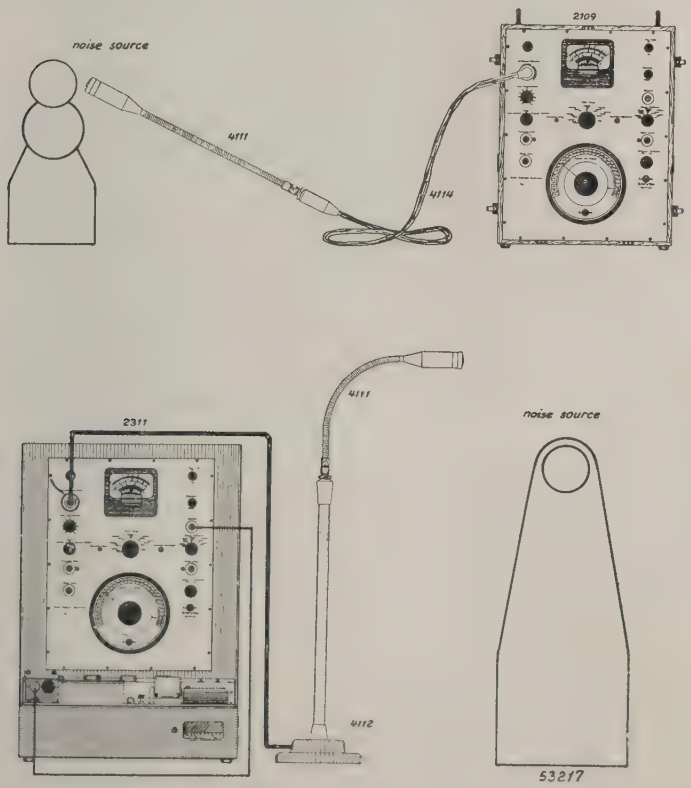

Fig. 25. Connection of Condenser Microphone to Audio Frequency Spectrometer Type 2109 and Audio Frequency Spectrum Recorder Type 2311.

Fig. 26 shows the spectrogram of noise from a lathe. The three different curves are recorded with different writing speeds on the recorder. The curve

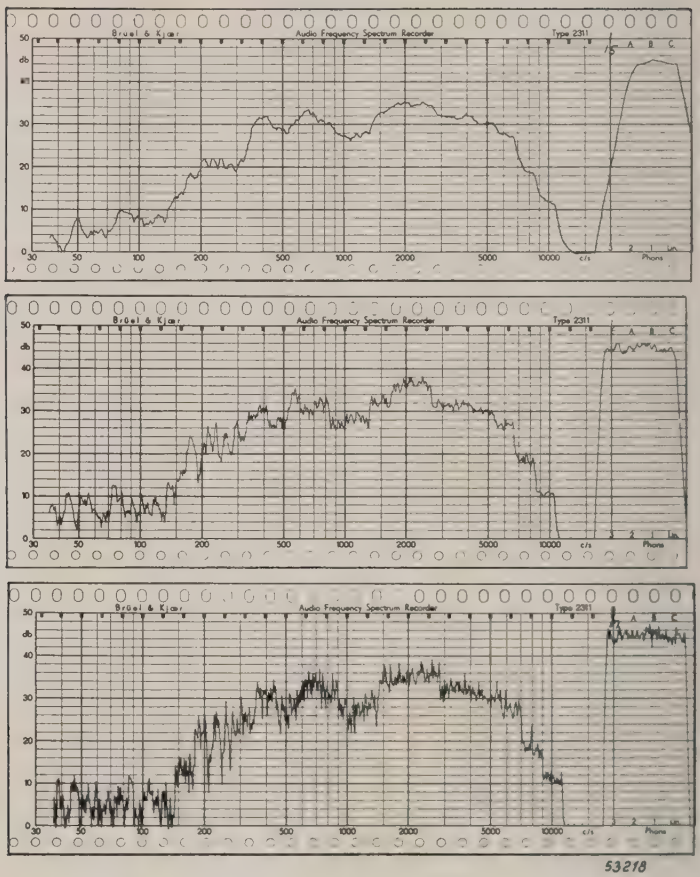

Fig. 26. Spectogram of noise from a lathe, taken with three different writing speeds: 50, 200 and 700 db/sec. The 50 db potentiometer is used. Zero level. $2 \cdot 10^{-2}$ ubar.

is smoothed out considerably with low writing speed on the level recorder and with high writing speed all the small variations in the sound become very pronounced. Note the fact that the irregularities with sound which is recorded with a linear characteristic are considerably lesser than the irregularities in the single band, and that the irregularities in the single band are greatest for the lower frequencies and least for the higher frequencies, quite

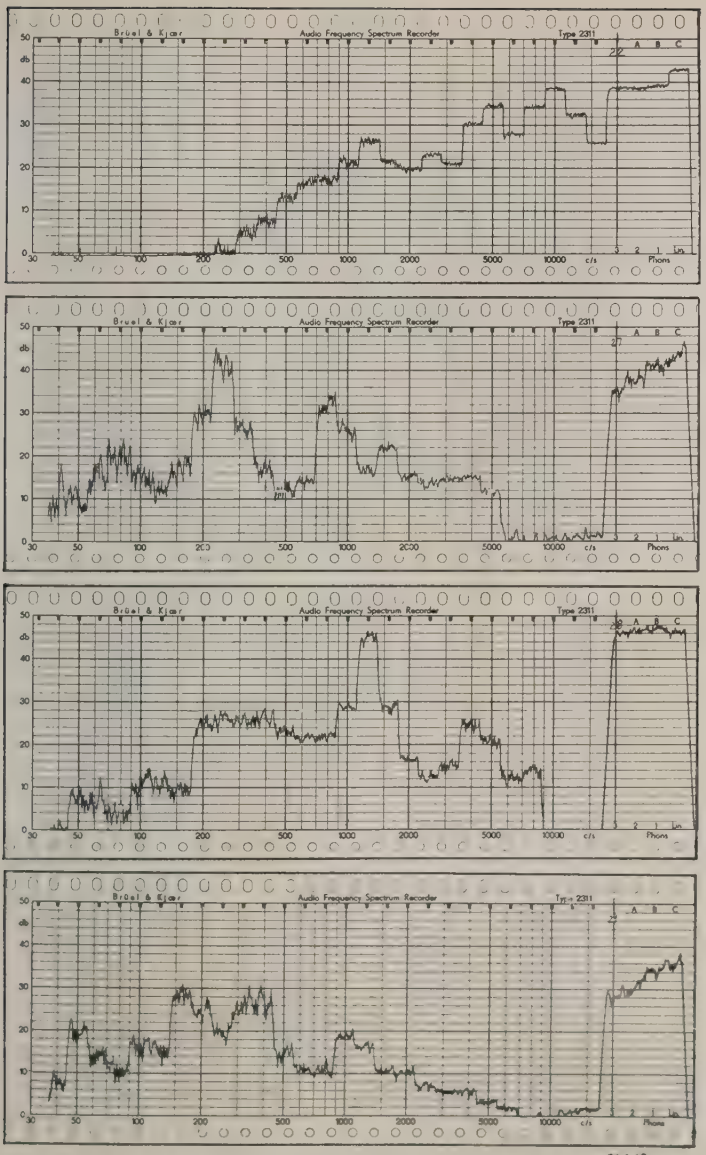

Fig. 27. Spectogram of
1) Air streaming from piping. Zero level: $6 \cdot 10^{-2}$ µbar.
2) Electric motor on stamping machine. Zero level: 10^{-2} µbar.
3) Motor for small drilling machine. Zero level: 10^{-2} µbar.
4) Motor for large drilling machine. Zero level: 10^{-2} µbar.
All recorded with 50 db potentiometer.

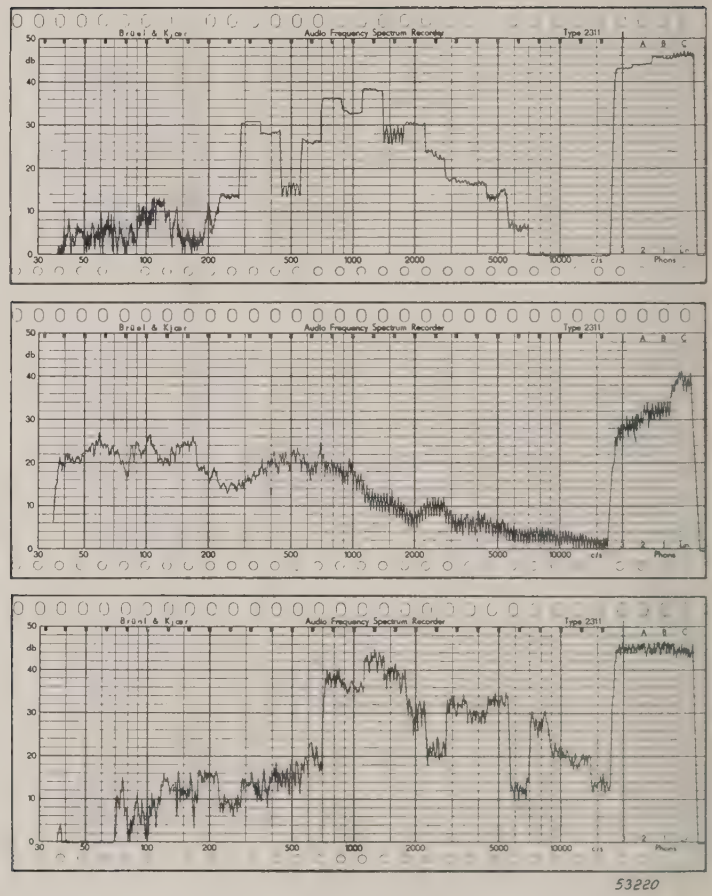

Fig. 28. Spectogram of

1) Double toned automobile horn. Zero level: 1 μbar.

2) Watch P7R 12348. Distance 50 cms. Zero level: $6 \cdot 10^{-4}$ μbar.

3) Alarm clock ringing. Zero level: $2 \cdot 10^{-2}$ μbar.

in accordance with the general statistical theory for the reflection of sound waves in enclosed spaces. Fig. 27 above shows the characteristic spectrum for air streaming from a system of pipes. It will be seen that this noise consists almost entirely of high frequencies. The three next spectrograms are all taken on electric motors, and it will be seen how varied the spectrograms are

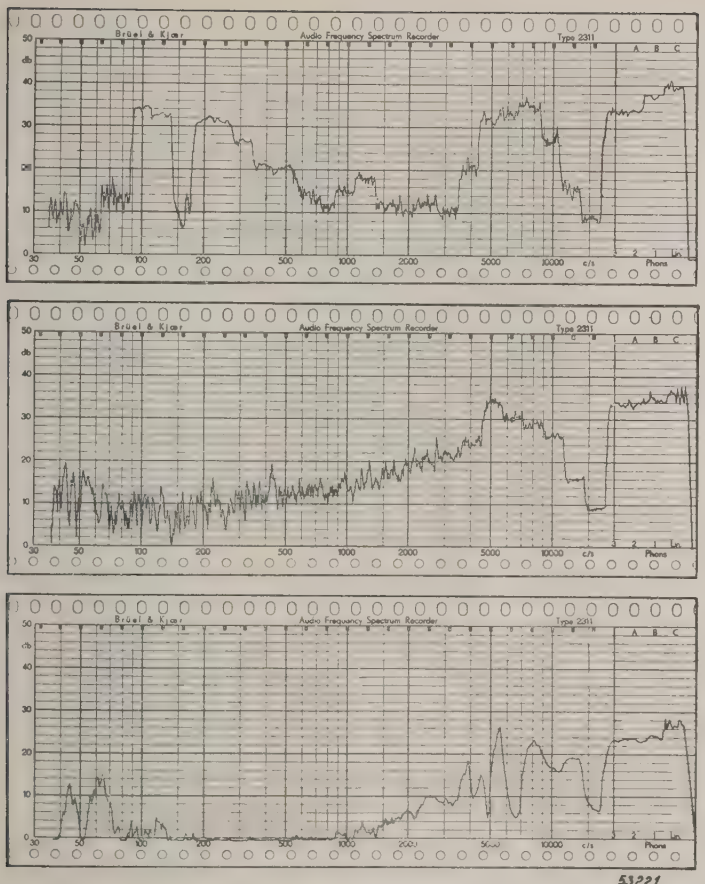

Fig. 29. Spectogram of speech sounds:

1) a as in father.
2) z as in zero.
3) s as in Mississippi.
Zero level 10^{-2} μbar.

Fig. 28 shows different characteristic sounds, above a double toned automobile horn, in the middle the sound from an ordinary wrist watch taken at a distance of approx. 20 ins. Note the very weak zero level. The Spectrum Recorder has been working here just at the limit of its own noise level at the lowst level it is possible to analyse. The lowest diagram shows an alarm clock ringing.

Fig. 29 shows the spectogram from some characteristic speech sounds. These spectrograms are taken with the highest speed of the recording paper, and as a result of this with a very great writing speed on the level recorder. The zero level given on the figure, expressed in μbar, refers to the db scale to the left on all the spectograms, which means that it is possible to read off direct the sound pressure in db above the given zero level within each frequency band.

Noise-Measurement with Condenser Microphone 4111.

The determination of absolute sound pressure expressed in μbar is useful for many physical investigations, but the sound pressure at different frequencies does not however immediately give an indication of the human ear's perception of the sounds' strength, as the ear is less sensitive to sounds of both low and very high frequency in comparison with the middle frequencies. This variation of sensitivity with frequency is very complicated as the absolute sound level also plays an important role. Sounds that seem to the ear to be equally loud are said to have the same subjective strength or loudness. Loudness is expressed in phons. In determining the loudness, the sound is compared with a tone of 1000 c/s whose physical energy is adjusted so that the sound and the 1000 c/s tone appear to the ear to be of equal strength. The loudness, expressed in phons, of the sound in question is then equal to the physical intensity of the 1000 c/s tone expressed in db above 2×10^{-4} μbars, or what is the same, in db above 10^{-16} watt/cm^2. At 1000 c/s, therefore, phon scale and

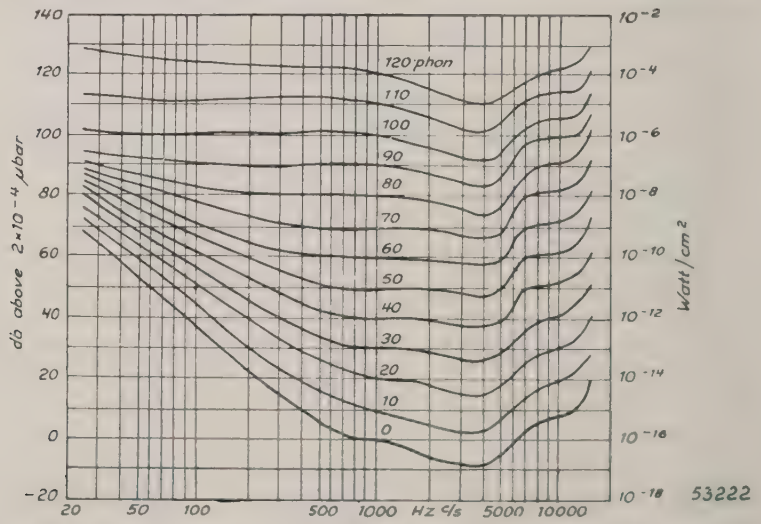

Fig. 30. The sensitivity curves for the human ear (Fletcher and Munson).

decibel scale become identical, but at all other frequencies they will be different. Fig. 30 shows the sensitivity curves of the ear.

In order that a sound-pressure meter should be able to measure the sound level in phons instead of μbar, it is necessary that the instrument should have such frequency characteristics that the low and very high frequencies be depressed in a manner corresponding to fig. 30. In practice it is sufficient to have three different characteristics each effective in their own level range. In Europe the characteristics set down in DIN 5045 are used, and in America the slightly divergent standards set down in ASA Z24.3. The various frequency characteristics are drawn in fig. 31 and it will be seen that the deviations are only noticeable for frequencies under 100 c/s, and it is happily the case that the tolerances permitted both for the European and American standards are so great that it is possible to give an instrument frequency characteristics which satisfy both Standards' requirements. The Standards set down also contain requirements for the sound-level meter's dynamic characteristics, frequency addition and overload safety factor. All these requirements are satisfied within the permitted tolerances in Spectrometer 2109 when equipped with a Condenser Microphone type 4111. The Spectrometer is equipped with 4 frequency characteristics for use in noise measuring, which all are shown in fig. 10.

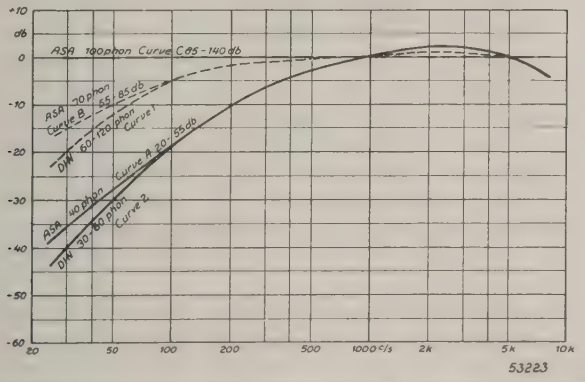

Fig. 31. The standardized frequency characteristics for sound level meters.

The noise measurements themselves are carried out just as described for measurements of sound pressure, but instead of reading off the deflection in mV and converting to sound pressures, the deflection is read off on the instrument's db scale and to this is added the phon value farthest out on "Meter Range" and "Range Multiplier". All the three figures have to be added together. Further to this the usual correction must be made for the sensitivity of the Condenser Microphone.

One of the three following produres can be chosen:

1st Method. Specially chosen when noise measurements are only seldom made.

a) The Spectrometer is adjusted as usual to the red mark, and will then be correct in relation to voltage.
b) From the Condenser Microphone's sensitivity expressed in mV μbar a number K in phons is calculated which must be added to the collected readings. One starts from the phon-scale definition of loudness, which at 1000 c s is the number of db above 2×10^{-1} μbar, corresponding to the fact that at 1000 c s 1 μbar = 74 phons. In this way the phon value which must be added to the reading can be calculated.

$$K = 14 - 20 \log \frac{\text{Sensitivity in m V}/\mu \text{ bar}}{1 \text{ m V}/\mu \text{ bar}} \quad \text{(phons)}$$

K = 0 when the microphone sensitivity is 5 mV/μbar.

2nd Method. Used when many measurements must be made, and the noise strength to be measured is not under 30 phons.

a) Correction factor K calculated as explained in Method 1.
b) Analyzer's sensitivity adjusted (10—K) db *below* the red mark.
c) To the phon value read off — scale reading in db + both "Meter Range" and "Range Multiplier"s phon index, add exactly 10 phons.

3rd Method. Used both with noise strengths under 30 phons and when it is not wished to add any correction to the individual measurements.

a) Correction factor K is calculated as in Method 1.
b) Spectrometer's sensitivity is increased by adjusting to K db *above* the red mark.
c) The loudness in phons = Scale reading in db + "Meter Range" and "Range Multiplier"s phon index.

In order that this method can be used it is necessary that the microphone's sensitivity is so great that K is a small number, otherwise it might not be possible to turn up the sensitivity of the Spectrometer high enough. A disadvantage with this method is that the negative feedback in the Spectrometer's amplifier makes it less precise and increases the difficulty with hiss and microphonics.

Weighted Spectrograms.

Almost every time a noise level measurement is taken it is necessary to analyze the frequency composition of the noise. However, a curve of sound pressure in μbar against the different frequencies cannot be used directly to judge the most disturbing frequency ranges. The spectrograms must first be corrected to the ear's frequency sensitivity by means of the ear-sensitivity curves of fig. 30. When the spectrogram has been corrected in this way it is described as "weighted" with reference to the ear's sensitivity. It is important that the appropriate level-curve be chosen for the calculations.

An example is shown in fig. 32, where the thin recorded curve shows the sound pressure as a function of frequency, for noise from a grindstone. The total noise was approx. 65 phons, so the 60 phon curve of fig. 30 is used for calculating the weighted spectrum. The calculations are seen above the

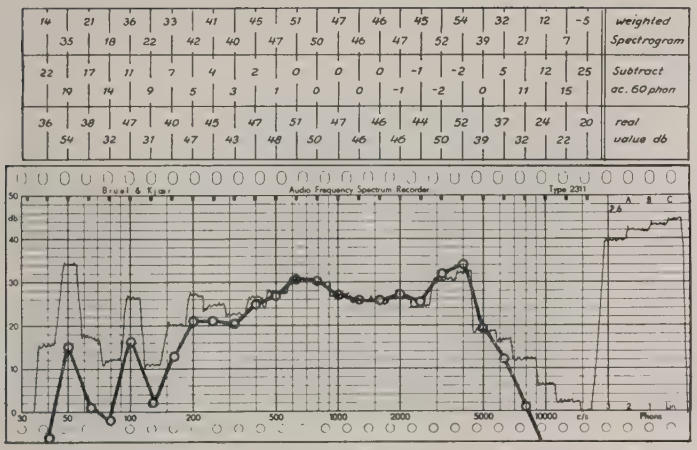

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Fig. 32. Spectogram of sound pressure in noise from a grinding machine (fine curve) and the same spectogram weighted with reference to the sensitivity of the ear (heavy curve).

recorded curve, and the result is shown drawn in on the curve as round circles connected by a heavy thick line. It is clearly seen that that noise which measured in μbar was strongest at quite low frequencies, when judged subjectively was most powerful in the middle range, the lower frequencies having less importance for the human ear at the noise level in question.

Measuring of Acoustic Noise from Small Objects.

Measuring noise levels and the determination of acoustic spectrograms of noise from small objects like domestic apparatus, small electrical motors, fluorescent lamp mountings etc. is difficult, because the level of the noise to be measured is so small that it is near the limit of the technically possible.

To increase the acoustic effect from the objects, and reduce external disturbances, it is recommended that the objects be placed in a special oblique-angled measuring box or a small measuring room with very hard sound reflecting walls. A room with a volume V of about 2 m^3 and with walls, floor and ceiling constructed of 10 cm concrete, covered internally with smooth and hard tiles, is very suitable. The reverberation time T can easily be brought up to about 2 sec, and with the help of small resonators can be adjusted for constancy over a frequency range of from 60—5000 c/s.

With a 2 sec reverberation time the total absorption in the measuring space is

$$\Sigma\, a\, S = A = \frac{0.16\, V}{T} = 0.16\ m^2$$

The intensity in the room is

$$E = \frac{4\,N}{c\,A}$$

where N is the total energy radiated from the test object, c is the velocity of sound. A point source of sound with the same radiation intensity placed in a sound-absorbing chamber will at a distance R give an intensity

$$E = \frac{N}{c\,4\pi R^2}$$

We thus find from the above example that the distance R_0 which gives the same sound level as in the sound reflecting measuring room is

$$R_0 = \sqrt{\frac{A}{16\,\pi}} = 0.06 \text{ m}$$

As most test objects are of much greater dimensions than this distance, it is not possible to measure in a sound-absorbing chamber at such a small distance and have the various components of the noise represented. In order to measure in a sound-absorbing chamber the measuring distance must be about 1.2 metres, which reduces the sound pressure being measured to 1/20.

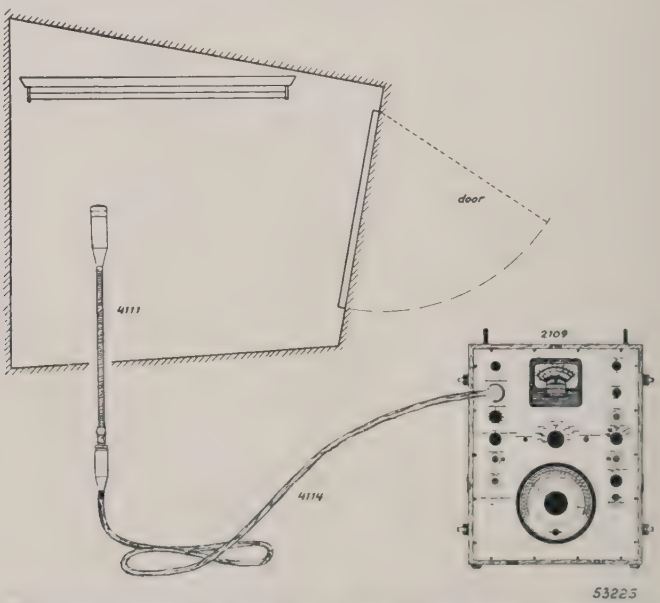


Fig. 33. Measuring small objects like domestic equipment, fluorescent lamps etc. in special reflecting test room.

Fig. 33 shows a sketch of a very practical measuring room with oblique angles. For such a reflecting box the condenser microphone with extension cable 4114 should be used.

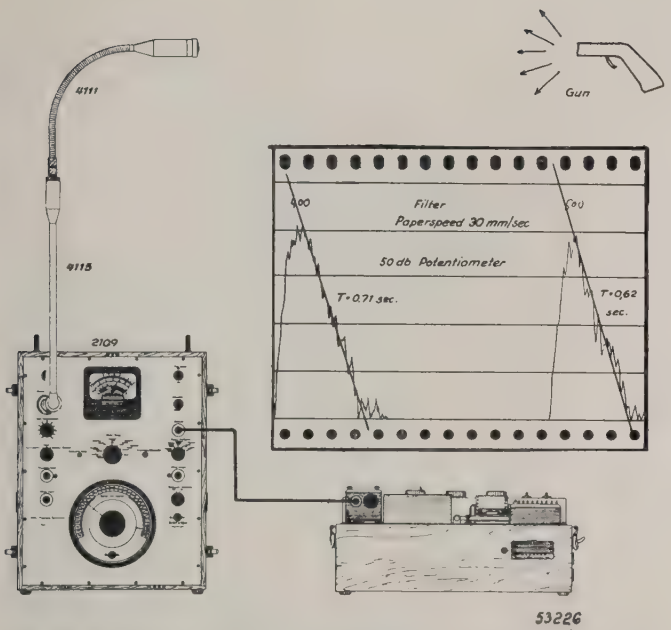


Fig. 34. Measuring reverberation time with a gun as sound source.

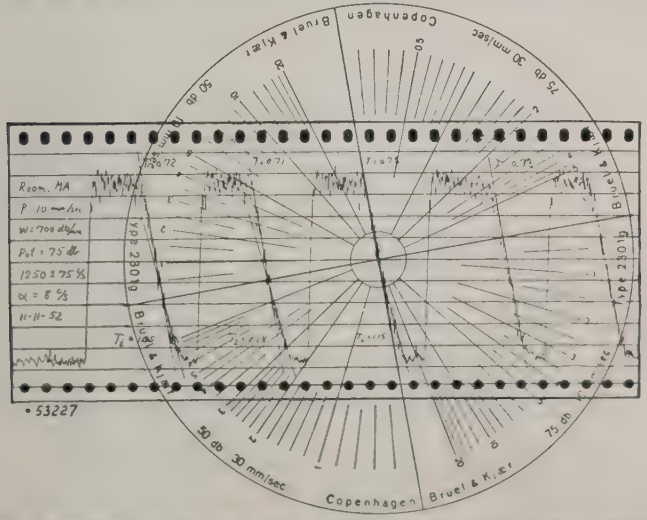
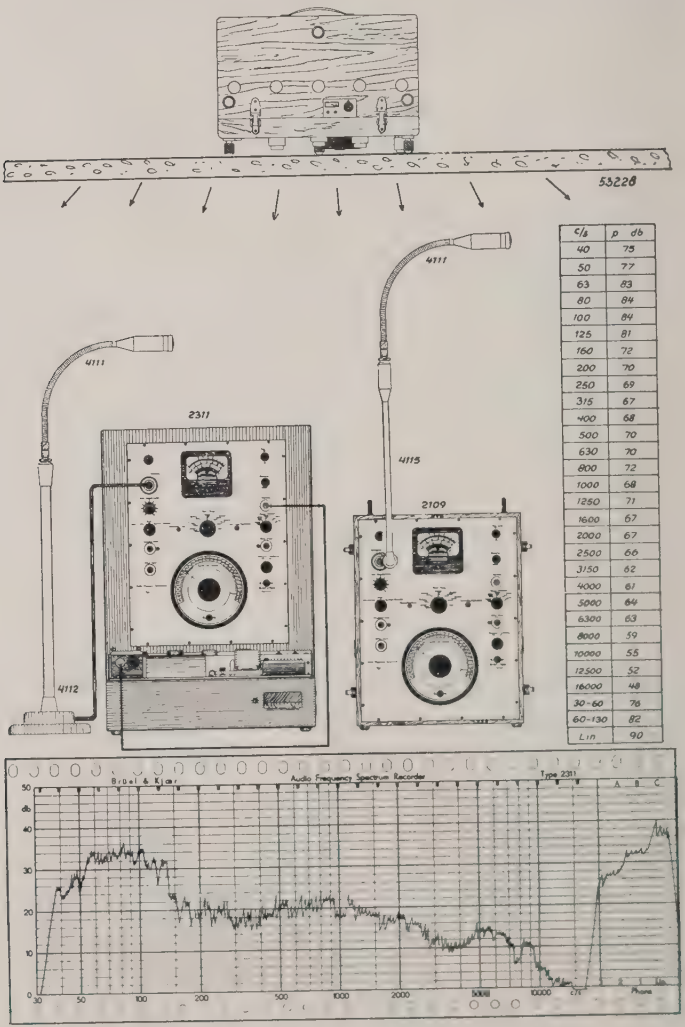


Fig. 35. Measuring reverberation time with Protractor 2361. Curves taken with BFO Type 1012 with warble tone as sound source.

Measurement of Reverberation Time.

When measuring reverberation time with a gun used as a sound source, it is necessary to have selective amplification when recording the level curves with the Level Recorder type 2304. The set-up is shown in fig. 34, where



c/s	p db
40	75
50	77
63	83
80	84
100	84
125	81
160	72
200	70
250	69
315	67
400	68
500	70
630	70
800	72
1000	68
1250	71
1600	67
2000	67
2500	66
3150	62
4000	61
5000	64
6300	63
8000	59
10000	55
12500	52
16000	48
30-60	76
60-130	82
Lin	90

Fig. 36. Measurement and analysis of impact sound.

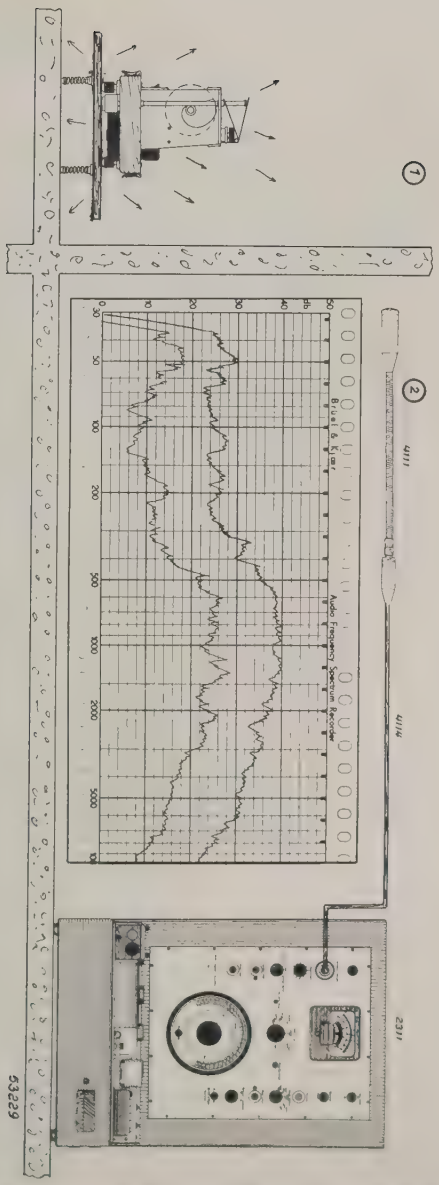


Fig. 37. Measurement of airborne sound insulation by using an impact sound generator as "white noise generator".

some typical reverberation curves are also given. It is recommended to take at least 3—4 shots in each frequency band. Also when using a Beat Frequency Oscillator with warble tone as sound source it is strongly recommended to have selective amplification, because it is possible here to record the reverberation curves over a much larger level range than when using a linear amplifier after the microphone. In fig. 35 are shown some typical reverberation curves. When the reverberation curves are recorded over a large level range it often shows up that the reverberation curves are a little curved in the last part, indicating some flutter echo in the rooms. On the figure are shown the two different reverberation times got from the upper and lower part of the curves. At the same time the use of the Protractor 2361 is shown.

Measurement of Impact Sound.

The sound insulation of a floor for impact sounds is estimated by placing a standardised impact sound generator on the floor, and measuring the sound intensity L in the room below for various frequency bands. In the "Tentative Standards" for these measurements it is recommended to use 1/3-octave filters for the estimation of the sound pressure, and it is recommended that the results be given in the form of a curve as a function of frequency or in tabular form as shown in fig. 36. The effective tapping level in a specific frequency band will then be given by the equation

$$L_{eff} = L - 10 \log \frac{T}{0.5}$$

where T is the measured reverberation time in seconds in the receiving room in the frequency band. If one wishes to express the tapping level by a single figure L_A, this can be calculated by means of a known described method, but it is always recommended to take a spectrogram of the sound under the floor in question, as this spectrogram is very important for judging the floor's quality.

Insulation Measurement of Airborne Sound with an impact sound generator.

Fig. 37 shows a handy and simple method for the measurements of airborne sound insulation of walls and floor partitions in buildings.

The air-borne sound insulation of the partition between room 1 and room 2 is measured by producing a high sound level containing almost all acoustical frequencies by placing an impact sound generator on a wooden board which again is placed on springs, so that the total sound energy from the impact sound generator is radiated as air-borne sound and only a very small amount as impact sound.

With the Spectrometer and the Condenser Microphone the sound pressures at different frequencies are first measured in room 1 and then in room 2. From the difference between the two readings the air borne sound insulation D is found as a function of the frequency, when correction is made for the absorption of the receiver room according to the formula

$$D = 20 \log \frac{p_1}{p_2} + 10 \log \frac{F}{A_2}$$

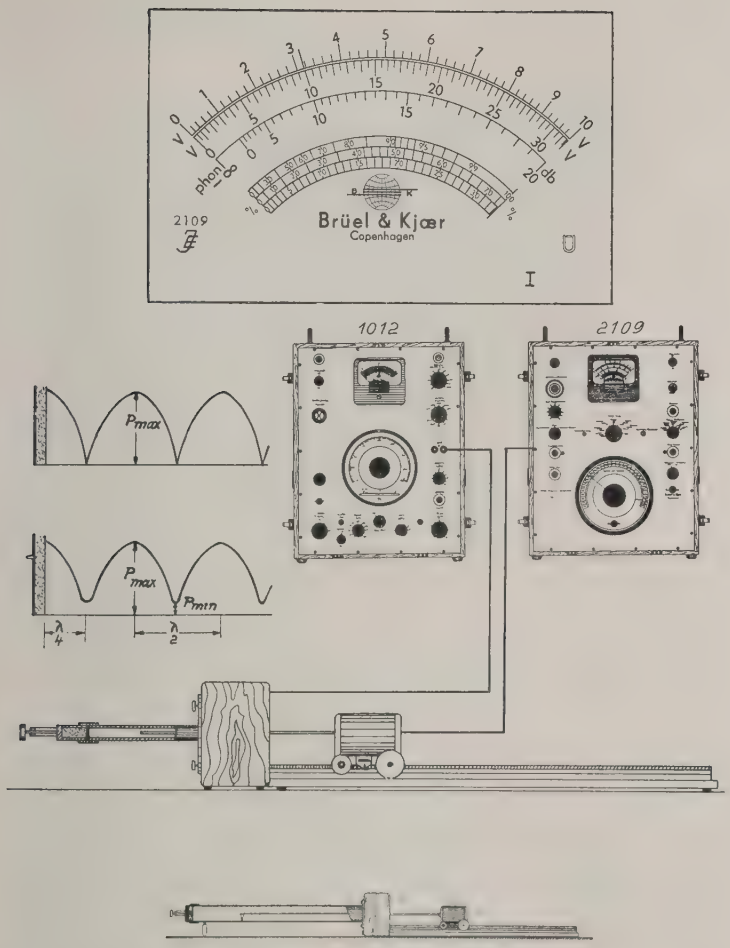


Fig. 38. Measurement of acoustic absorption coefficient with the Standing Wave Apparatus 4002.

where F is the area of the wall between room 1 and 2 and A_2 the absorption of the receiver room, both measured in the same units.

If the sound pressure of the noise as a function of frequency is recorded in

the two rooms, the sound pressure relation between the two rooms can be directly estimated from the difference between the two curves, and thus the figure for the wall's insulation, D.

Measurement of Acoustic Absorption Coefficient.

With the Standing Wave Apparatus type 4002 the acoustic absorption coefficient of small samples can be measured by inserting them at the end of the measuring tube. See fig. 38.

The apparatus is connected, as shown, with a beat-frequency oscillator, for example type 1012, and the microphone built into the microphone carriage is connected to the Spectrometer. Standing waves are produced in the measuring tube, and the maxima and minima can be measured by moving the microphone carriage. The ratio between the maxima and minima determines the acoustic absorption coefficient of the sample. The Spectrometer's indicator meter is equipped with a set of extra scales, from which the absorption coefficient can be read directly.

At the top of the figure can be seen the instrument scale with three ranges, 0 to 100 %, 0 to 70 % and 0 to 30 %. The microphone carriage is first placed at a point where the sound pressure is a maximum, then the Spectrometer's amplification is adjusted so that the pointer is at full deflection. The microphone carriage is then displaced to a minimum position, and the absorption read in per cent directly from the Spectrometer scale graduated 0—100 %. By increasing the amplification by 10 of 20 db before taking the minimum reading, the absorption coefficient can be read on the scale 0—70 % or 0—30 %.

Standing Wave Apparatus type 4002 is equipped with 2 measuring tubes, one with a frequency range covering 95 to 1800 c/s and the other covering 800 -6500 c/s. Acoustic absorption materials whose coefficients range from approximately 4 % to 100 % can be measured with this apparatus.

For further information see the instruction book for the Standing Wave Apparatus type 4002.

Recording and Analysis of Fluctuating Noise.

In many workshops or offices the noise level varies very considerably, and if the noise level is measured in such places by taking a single reading, a serious error will often be made because of these fluctuations in the level, and if one furthermore wishes to take a spectrogram, the fluctuations will be still greater, as the noise variations in a small frequency band are always much greater than the average value from all the frequencies. In such a case it is necessary to record both spectrograms and noise level over a relatively long period of time, so that a satisfactory average figure can be obtained, and so that the noise peaks can also be observed, which is of particular interest from a health point of view. With the recording equipment consisting of Condenser Microphone 4111 and the Audio Frequency Spectrum Recorder 2311, there are two

possible methods to follow. The first way is to take a whole series of spectrograms one after the other, as shown for example in fig. 39, where the recording of each spectrogram has taken approx. 24 sec. When a long series of these spectrograms has been obtained for a given room or workshop, they can be compared and the maxima for the different frequencies found from them. This method requires much time, and almost as good results can be obtained by using the method shown in fig. 40, where a spectogram with a very slow paper speed has been taken in a workshop, i. e., the recorder is allowed to stay on each individual filter a very long time. The curve shown has taken 20 minutes in all to record. In this way the total number of fluctuations is obtained for each filter, and also the maximum sound strength effective in each frequency band. If very precise measurements are desired, these recordings should be repeated over a longer period, for example a whole day, with three recordings per hour.

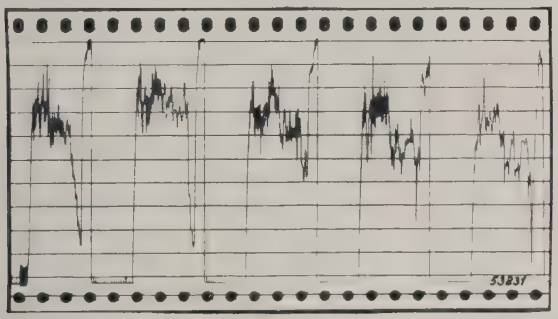


Fig. 39. Continuous recording of spectograms and noise levels.

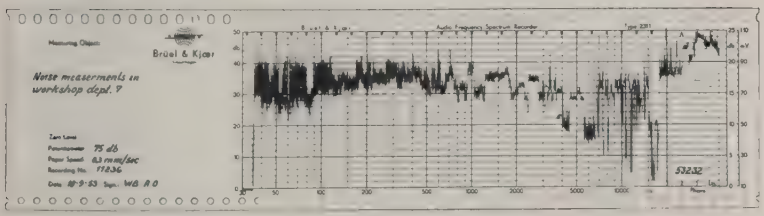


Fig. 40. Long time recording of spectograms and noise levels.

Control of Hearing Aids.

Fig. 41 shows a complete set-up for the control of hearing aids. The hearing aid is placed just in front of the opening in the Artificial Voice type 4210, both being placed in a small soundproof box lined with absorbing material. The artificial voice 4210 contains a strongly damped loudspeaker with a good.

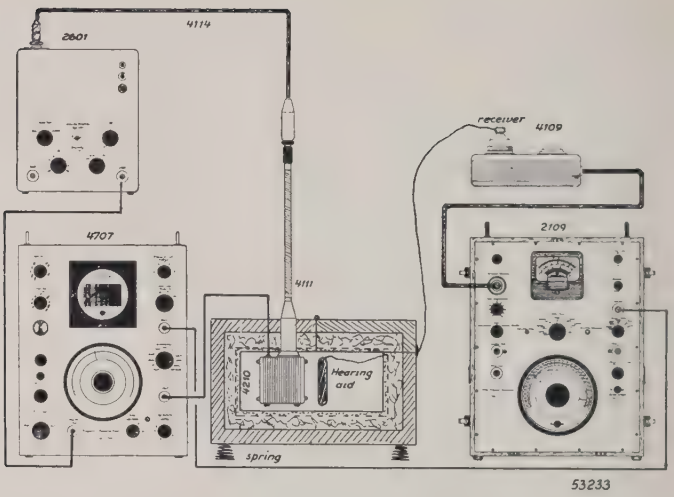


Fig. 41. Control of hearing aids.

flat frequency characteristic, and a regulating microphone, which is connected to the compressor input in the Frequency Response Tracer 4707 via the cathode follower in 4111 and the Microphone Amplifier 2601. The loudspeaker in 4210 is connected to the beat frequency oscillator in the frequency response tracer. By this means, because of the compressor in 4707, it is ensured that the sound pressure be kept constant just in front of the artificial mouth. The hearing aid is placed here, with its receiver placed on the Artificial Ear 4109, which is connected to spectrometer 2109. The output from the spectrometer is then connected to the input of the tracer, and when the tracer's BFO is turned by its motor, the total frequency curve of the hearing aid for constant sound pressure will be seen on the tracer's cathode ray screen. As the various Standards suggested for the measuremens of hearing aids prescribe that these measurements be made with a very small sound pressure, it is necessary to have very effective insulation against external noise penetrating into the sound absorbing box.

This is therefore equipped with very thick walls and placed on springs, so that also impact sound cannot get into the box. The advantage of using spectrometer 2109 as amplifier for the Artificial Ear 4109 is that immediately following the recording of the frequency curve, a number of distortion measurements can be carried out, and this is of great importance for judging the hearing aid.

Direct Recording of Harmonics.

Fig. 42 shows how one can directly record with the help of the Automatic

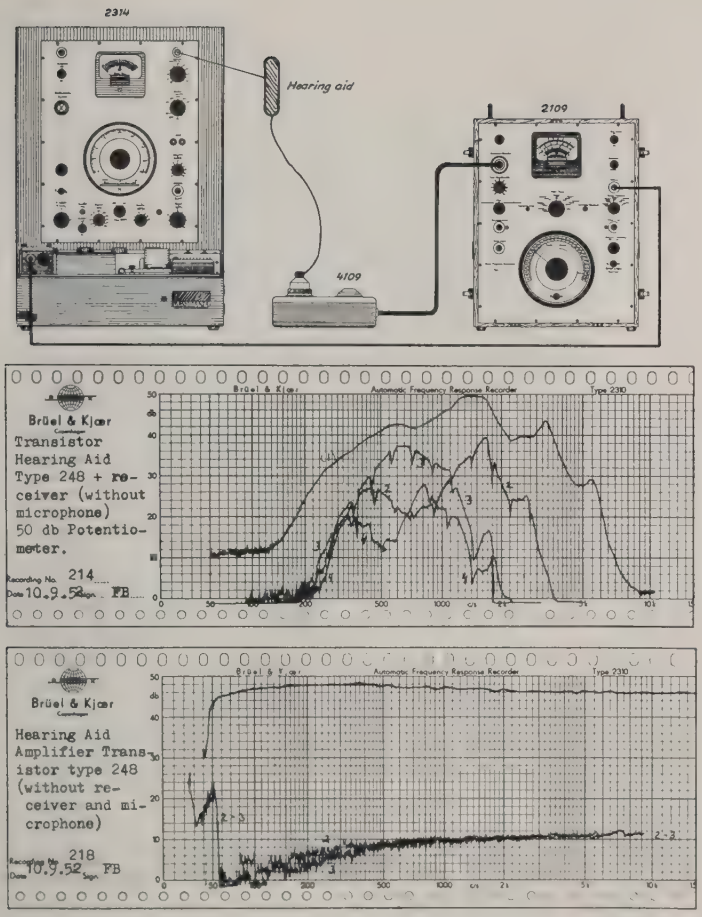
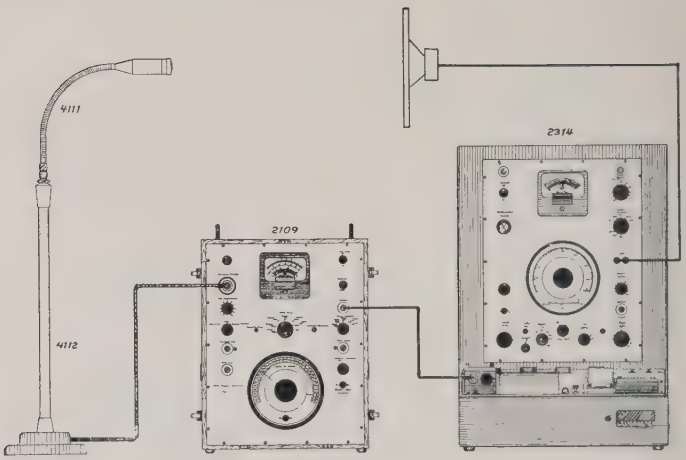


Fig. 42. Recording of fundamental and lowest harmonics: above, of hearing aid with receiver, and below, of hearing aid amplifier of the transistor type.

Frequency Response Recorder 2314 and Spectrometer 2109 not only the frequency characteristic of the fundamental (1), obtained on setting the spectrometer on linear characteristic, but also the second, third and fourth harmonics of that voltage fed to the spectrometer.

To record the second harmonic the main scale on the spectrometer is shifted by hand so that the spectrometer is always 1 octave in advance of



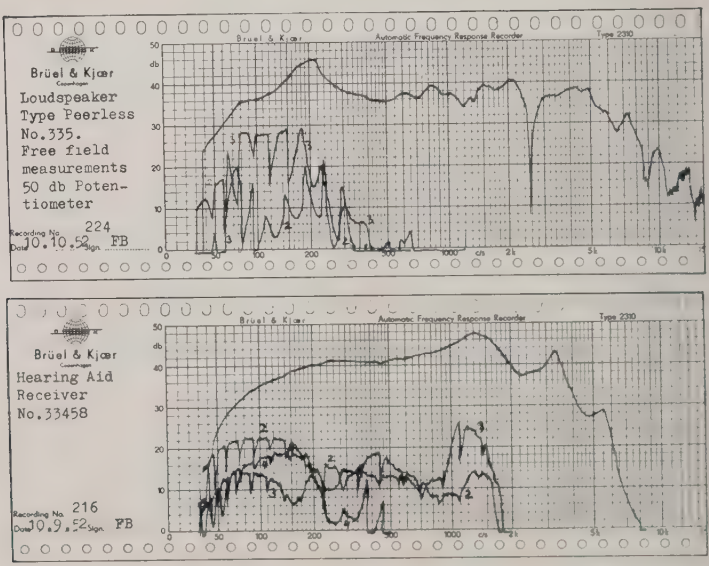


Fig. 43 Above: recording of loudspeaker's frequency characteristic and the lowest harmonics. Below: Frequency characteristic and harmonics of hearing aid receiver.

the BFO scale on 2314. It is necessary to note in advance at which frequencies the spectrometer is to be shifted from the one filter to the next, and shift exactly at the moment. Moreover the zero-adjustment of the oscillator should be carried out with extreme care, in order to avoid a discrepancy between the frequency as indicated on the dial of the BFO and the fixed cut-off frequencies of the filters.

In order to carry out this shift with sufficient precision, a relatively long time must be allowed for running through the whole frequency range. For example, 2314 could be suitably adjusted to give a paper speed of 1 mm/sec. If it is wished to record the 3rd harmonic, the spectrometer should be held $1^1/_2$ octaves ahead of the BFO, for the 4th harmonic, two octaves, and so on.

Filter	*2nd harmonic*	*3rd harmonic*	*4th harmonic*
40			
50	22,3 hz		
63	28,1		
80	35,4	23,6 hz	
100	44,6	29,7	22,3 hz
125	56,1	37,4	28,1
160	70,6	47,1	35,3
250	89	59,3	44,4
200	112	74,6	55,9
320	141	93,9	70,5
400	178	118	88,7
500	223	149	112
630	281	187	141
800	354	236	177
1000	446	297	223
1250	561	374	281
1600	706	471	353
2000	890	593	444
2500	1120	746	559
3200	1410	939	705
4000	1780	1182	887
5000	2230	1490	1120
6300	2810	1870	1410
8000	3540	2360	1770
10000	4460	2970	2230
12500	5610	3740	2810
16000	7060	4760	3530

On fig. 42 are seen some curves from a hearing aid with transistor amplifier and terminated by a telephone receiver, placed on the Artificial Ear 4109. By rolling back the registering paper all the harmonics and the fundamental can be recorded on the same paper section, giving a very clear picture of both the frequency characteristic and the harmonic content. With the measure-

ments in question a 50 db potentiometer was used, and it can be seen that the distortion has been very great over a very wide frequency range. Beneath, the same measurements are shown, repeated for the transistor amplifier alone. It is seen that the 2nd and 3rd harmonics almost merge together into one curve, and that this curve lies a long way from the fundamental, i. e., the distortion has been slight. The harmonics lie 36—40 db below the fundamental, i. e., the distortion factor has been about 1—2 %. In fig. 43, above, can be seen the distortion measurements on a loudspeaker, and here both the 2nd and 3rd harmonics are outstanding at the lower frequencies. The curves are taken with constant current in the loudspeaker's speech coil. Below is shown a hearing aid receiver, and here it is seen that powerful 2nd, 3rd and 4th harmonics are present, particularly at the lower frequencies. In making these recordings it is impossible to avoid a little notch arising in the harmonic curves each time there is a shift in the filter in the spectrometer, but it is easy to distinguish between these regular disturbances arising from the shifts, and the natural irregularities in the curves themselves.

The exact frequencies, as indicated on the dial of the BFO, for shifting over to the next filter follow in the table below for the continuous recording of 2nd, 3rd and 4th harmonic.

Loudness and Loudness Level.

Loudness is a subjective quantity and cannot be measured exactly with any instrument. Loudness is defined as that aspect of auditory sensation in terms of which sound may be ordered on a scale running from "soft" to "loud". Loudness is chiefly a function of the sound pressure level, but is is also dependent on the frequency and the composition of the sound. The loudness of a sound is related to the total wave energy produced by the sound in the ear, whence it is sent to the brain.

The range of loudness is divided subjectively into equal unit steps called sones = 1000 millisones = 1000 loudness units. A loudness of a millisone corresponds to the threshold of hearing and a loudness of 10 sones is twice as loud as a loudness of 5 sones and 10 times as loud as 1 sone etc.

The loudness of a sound at a given sound pressure level at one frequency may be quite different from the loudness of a sound of the same level at a different frequency, but listeners can adjust the level of one tone to match the loudness of another. By such experiments a useful objective scale of loudness, called loudness level, is made.

Loudness level of a pure tone in phons is numerically equal to the sound pressure level expressed in db above 2×10^{-4} μbar of a 1000 c/s tone, which sounds equally loud.

Equal loudness contours for pure tones are shown in fig. 30.

The relationship between loudness in sones and loudness level in phons is given in fig. 44.

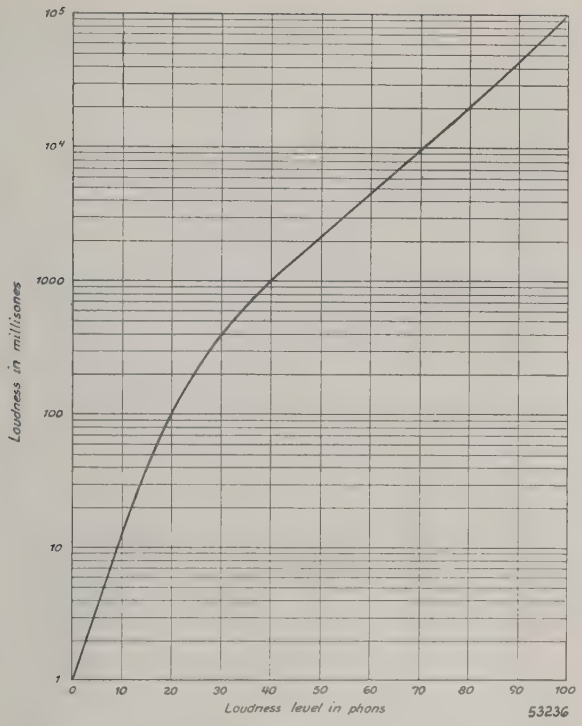


Fig. 44. Loudness in sones as function of the loudness level in phons.

This curve applies to sound of any frequecy, or combination of frequencies. If the loudness level of a sound is 40 phons, it will have a loudness of 1000 millisones, if the loudness level is 70 phons, it will have a loudness of 10000 millisones. A reduction of the loudness level from 70 to 40 phons corresponds to a tenfold change in loudness.

This relationship is of considerable practical interest in regard to the reduction of noise in rooms by sound absorption or by sound insulation. If, for example, the loudness level in a workshop by acoustical treatment of the ceiling is reduced from 72 phons to 63 phons, the average listener will judge the reduction from 12 to 6, which is the same as to the half or to 50 %.

Calculation of Loudness Level from Line Spectra.

If it is desired to calculate the loudness level in phons from a measured line spectrum constisting of a number of discrete frequencies, spaced relatively

widely, the two charts fig. 30 and 44 are used. The procedure is as follows:—

1) Determine from the chart fig. 30 the loudness level in phons of each discrete frequency according to the frequency and sound pressure in μbar.

2) Take the loudness level in chart fig. 44 and find for each discrete frequency the corresponding loudness in millisones.

3) Add the different values for loudness together.

4) Use this sum in fig. 44 to find the total loudness level in phons for the line spectrum.

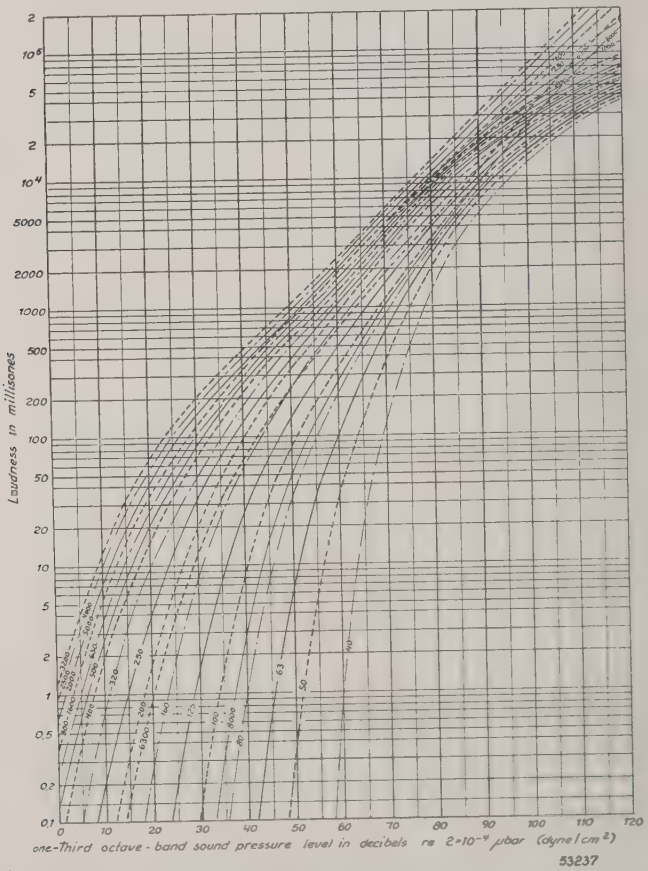


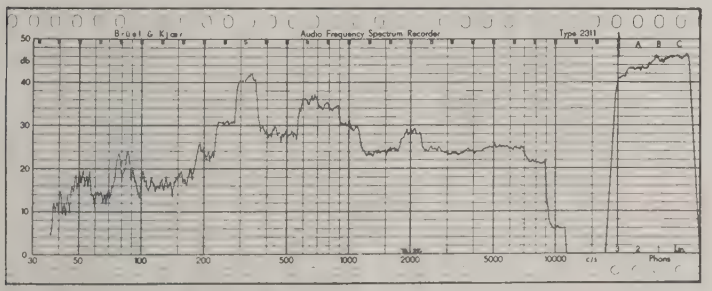
Fig 45 Loudness in millisones for ⅓-octave filters as a function of sound pressure level in db re $2 \cdot 10^{-4}$ μbar.

Calculation of Loudness Level from Continious Spectra.

With continuous spectra such as workshop noise, street noise etc,, the calculation of loudness level in phons from the pressure measured as a function of the frequency is much more difficult than with line spectra.

It is best to procede by calculating from specially constructed families of curves, of which an example is shown in fig. 45, the contribution to the loudness in sones from each frequency band. The magnitude of this contribution depends in a complicated manner on both the sound pressure level in the band and the frequency. Fig. 45 is effective for filters with a bandwidth of 1/3 octave. (Similar families of curves, but less detailed, and effective for octave filters will be found on page 524 of L. L. Beranek's "Acoustic Measurements").

Having measured the sound pressure in db above 2×10^{-4} μbar for each filter with 2109 or 2311, fig. 45 is taken and the total corresponding number in millisones is found for each filter. The loudness total in millisones is then the sum of the contributions from the separate frequency bands. The loudness level is found by referring back to fig. 44.



c/s	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3200	4000	5000	6300	8000	10000	12500	16000	Frequency in c/s
db	32	38	33	40	38	36	38	44	51	61	48	48	56	54	50	44	44	49	45	43	44	45	45	41	26	–	–	Sound pressure in db re 2×10^{-4} µbar
mS	–	–	–	1	5	9	42	180	400	1300	460	550	1150	1050	800	470	470	750	620	610	560	550	120	4	–	–	–	millisones

Total millisones: 10101 correspond to a loudness level on 71 phons. Instrument read: 67 phons

53238

Fig. 46. Spectrogram of a small lathe with calculation of its real loudness level

Fig. 46 shows the spectogram of a small high-speed lathe, and in the table under the figure the sound pressure level re 2×10^{-4} µbar is given. By using fig. 45 the corresponding sone values in the different frequency bands are found, these are added together, giving the total loudness in millisones, and this value is used in fig. 44 to give the loudness level in phons. As will be seen, this precisely calculated loudness level in phons does not correspond exactly with the value registered by the spectrometer, using the frequency characteristic curve B. In the sample calculated here the difference is 4 db. The explanation

is that it is not theoretically possible to construct an objective noise level meter which indicates directly the loudness level in phons as experienced by the human ear. For precise measurements it is therefore necessary to procede as described here, splitting the whole frequency range up into one-third octaves, and finding the contribution to the loudness from each frequency interval on its own, then adding the whole together, to give a total effect.

Analysis of Transients.

The Audio Frequency Spectrum Recorder 2311 or the combination of Spectrometer 2109 and Level Recorder 2304 is particularly suitable for the analysis of transients, as a recording is possible with this equipment giving amplitudes as a function both of time and frequency. This kind of analysis has shown itself especially valuable for transients of noise from rockets, guided missiles, low flying aircraft, motor vehicles etc., as well as of the vibrations or noise from periodically working machines, as for example drilling machines, large Diesel engines and so on.

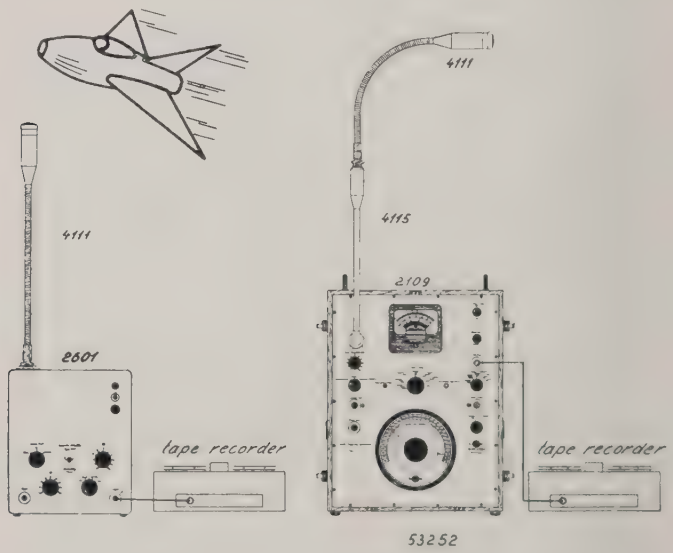


Fig. 47. Recording of transient noise on a tape recorder.

The methods is as follows:

The relatively short-duration noise to be analyzed is recorded on a good tape recorder, fig. 47. As microphone the Condenser Microphone 4111 is employed, and as amplifier the Microphone Amplifier 2601 or the Audio Frequency Spectrometer 2109.

After this, that part of the tape containing the noise one is interested in is cut out, folded as a loop and the ends glued to each other. The length of the loop should now be accurately synchronized with the time it takes for the Spectrometer to switch from one filter to the other.

In the following table the first row indicates the wheel position in the gear box of the Level Recorder, while the second row indicates the corresponding time each of the 31 steps of the Spectrometer takes before moving to the next. This table is valid for type 2311 and for the combination 2304 plus 2109 mechanically coupled together with the aid of Speed Multiplier 3004. The loop length is then the product of this time interval and the tape speed of the tape recorder. Lastly, the third row gives the different paper speeds necessary to record all the 31 analyses together on the preprinted paper

Wheel:	A	B	C	D	E	F	G	H	
Time per step:	0,48	1,6	4,8	16	48	160	480	1600	secs.
Paperspeed:	10	3	1	0,3	0,1	0,03	0,01	0,003	mm/sec.
Time for complete revolution:	0,4	1,33	4	13,3	40	133	400	1333	mins.
Time for scanning 35—18,000 c/s:	0,216	0,72	2,16	7,2	21,6	72	216	720	mins.

type 3601-3603. This results in a recording effacing the details of the transient noise per filter, but enabling an over all view of the energy distribution over the whole spectrum. Taking a higher paper speed will on the contrary show all the details in each filter band. Only in the first case does it pay to perform the recording automatically and to synchronize the automatic switching with the tape recorder by adjusting the loop-length; in the second case the recording

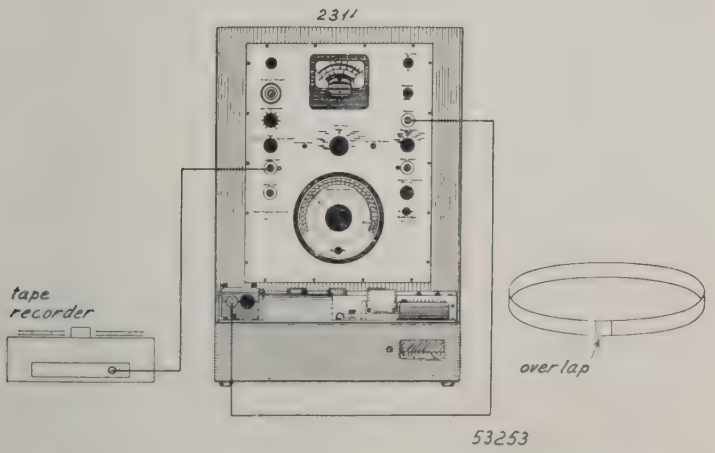
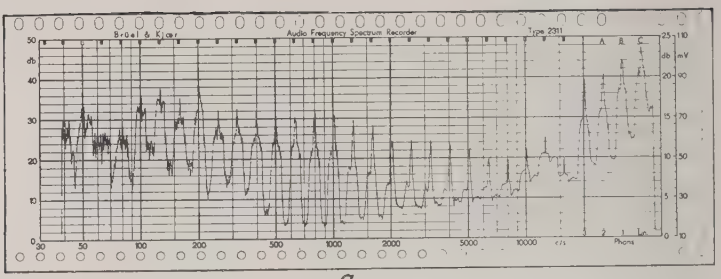
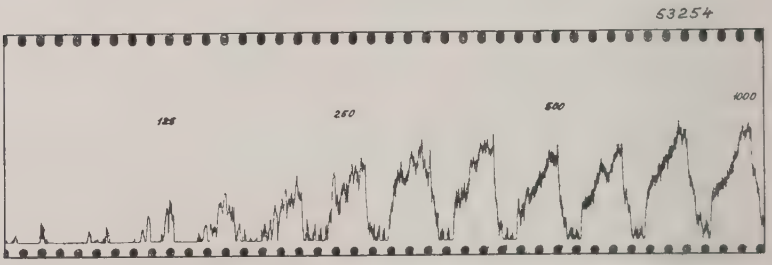
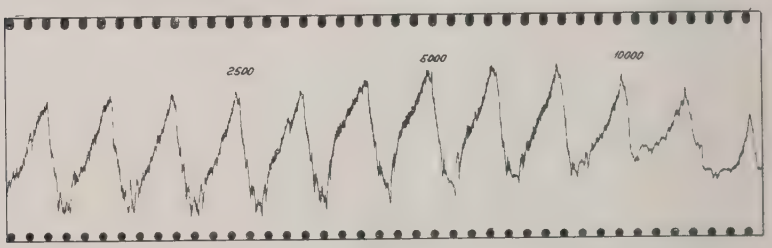


Fig. 48. Playing off a tape-loop for the recording of transient noise

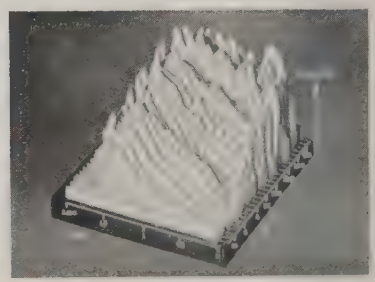


a





b



c

Fig. 49. Transient analysis of

a) a bang made in a small room,

b) a passing motorbicycle suddenly stopping,

c) idem b in a 3-dimensionel representation.

is easiest done with manual shifting. It is advisable to have the noise one is interested in only covering about 75 % of the total loop-length. Then at a small distance from where the ends are glued together the tape is touched by a point magnet, so that a clicking noise is heard when playing off the tape, fig. 48. The first time, this is done without actually recording, only measuring the time which the loop takes to circulate 31 times (by means of the heard click). This time should then correspond to 31 × the interval time as shown in the table and in case this is not exactly true, the loop-length should be altered. When this fits, the recording can be made.

If only recordings are made with higher paper speed than indicated in table 1, manual switching is recommended, together with the use of paper type 2350, 2351 and 2352 without preprinting. To localize the frequencies of the different filters afterwards on the recording strip some frequencies are recorded as lines by means of the push button frequency marker on the Level Recorder.

In fig. 49, 50 and 51 a series of characteristic examples of analyses of different sounds is shown, made in the way described.

Fig. 49 shows the transient analysis of a bang made in a small room. The over-all energy distribution of this noise is to be seen together with the course of the amplitude for each filter. The tape loop was in this case 30.5 cm long and synchronized with the combination wheel B and paper speed 3 mm sec., so that the paper type 3603 with its preprinted frequency scale could be made use of. The writing speed is 300 db/s.

Fig. 49 b is a recording without synchronization, the loop being so long that the whole phenomenon of a passing motorbicycle stopping suddenly could be recorded. W = 300 db/s. P = 3 mm/sec. With a paper speed of 10 mm/s the length of the recording per filter is sufficiently extended to make a 3-dimensional representation possible by cutting out each filter recording and placing these curves parallel behind each other perpendicularly on a third axis representing frequency. Fig. 49 c shows a picture of such a 3-dimensional noise spectrogram.

Fig. 50 gives 2 noise-analyses, one recorded at the motor of an automobile the other at the exhaust pipe. In both cases a synchronized as well as an extended recording were made (the latter only partly given here).

Fig. 51 at last shows the analysis of the word "Mississippi". Fig. 51 a gives the energy distribution, fig. 51 b some particular filters recorded with 10 times higher paper speed, showing for the high frequencies clearly the two double s parts, whereas for the lower frequencies this item vanishes completely, but on the other hand the vocals show up distinctly.

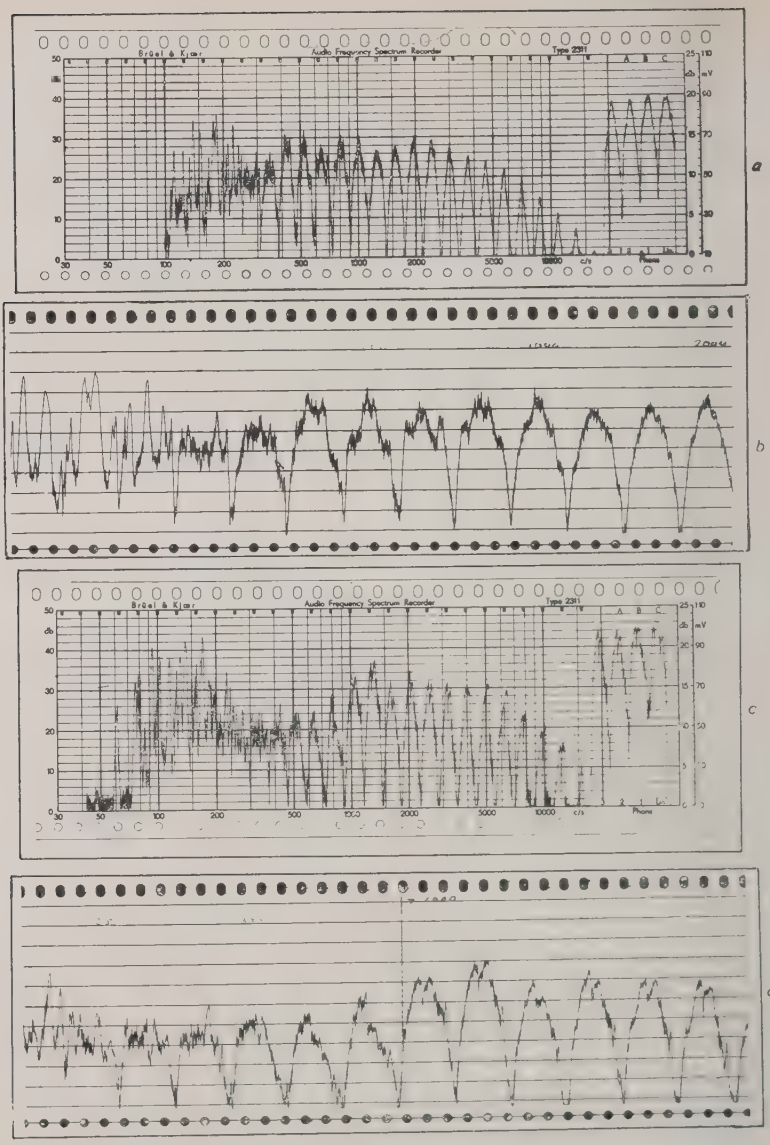
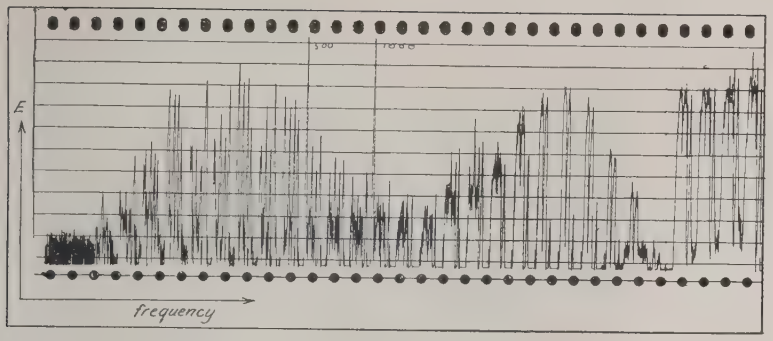


Fig. 50. a) Noise of an automobile recorded at motor loop 91.5 cm, wheel C, P = 1 mm/s, W = 300 db/s.
b) idem a. P = 3 mm/s.
c) noise of an automobile recorded at exhaust-pipe loop 91.5 cm, wheel C, P = 1 mm/s, W = 300 db/s.
d) id c. P = 3 mm/s.



a

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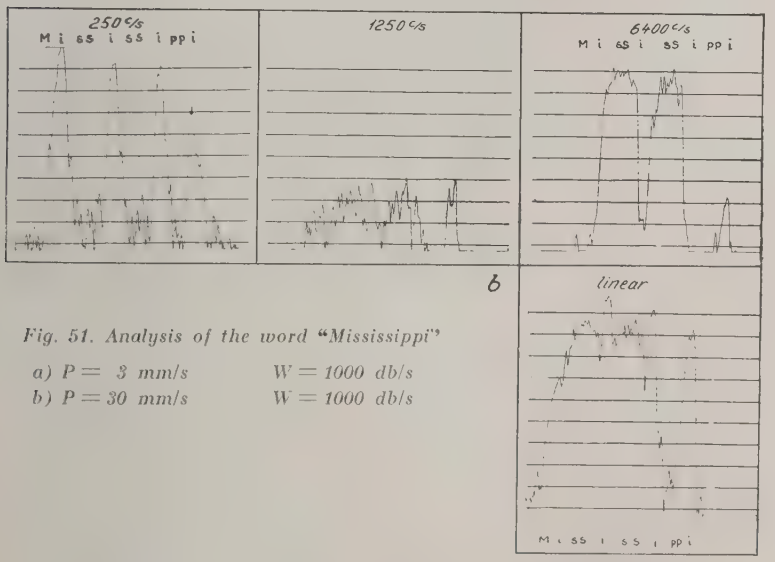


Fig. 51. Analysis of the word "Mississippi"

a) P = 3 mm/s *W = 1000 db/s*
b) P = 30 mm/s *W = 1000 db/s*

Specifications.

Audio Frequency Spectrometer type 2109.

Fixed Frequencies: 40, 50, 64, 80, 100, 125, 160, 200, 250, 320, 400, 500, 640, 800, 1000, 1250, 1600, 2000, 2500, 3200, 4000, 5000, 6400 8000, 10.000, 12.500, 16.000 c/s. The frequencies are read on an illuminated main scale.

Selectivity: Band width 1/3 octave.

The attenuation at frequencies 1/6 octave from the middle is approximately 3 db, except for frequencies under 100 c/s, where it is approximately 4 db.

The attenuation at 1/3 octave from the middle is approx. 20 db, except for frequencies under 160 c/s, where it is 12—18 db.

The attenuation at 1 octave from the middle is approximately 52 db, except for frequencies under 160 c/s, where it is 35—50 db.

The attenuation at frequencies more than 3 octaves from the middle is more than 65 db.

Frequency Accuracy: Better than 2 %.

Frequency Characteristics: As a linear amplifier in the frequency range 20—20.000 c/s the amplification is constant within ± 1 db, and ± 0.5 db in the range 50 -10.000 c/s. As a sound level meter the frequency characteristics are the internationally proposed characteristics at 0- -30 phons, 30—60 phons, and 60—130 phons, given in DIN 5045, or for the two last curves in ASA Z24.3.

Amplification: Maximum amplification gives fluu deflection (10 V on the output terminals) for 100 μV, and can be attenuated in steps of 10 db to 1000 V for full deflection. Input potentiometer for continuous gain control. Amplifier noise referred to the input and for maximum gain, approx. 15 μV with open input and approx. 5 μV with short-circuited input, and linear frequency characteristics.

A.C.hum: Approx. 2 μV for the amplifier, and up to 6 μV for some of the filters.

Meter: Linear scale, conveniently illuminated. Perfectly secured against overload. Dynamic characteristics according to DIN 5045.

Scales: Voltage scales 0—10 V and 0—31.6 V. Decibel or phon scale 0—20 decibels or phons. Three percentage scales for measurements of acoustic absorption coefficients.

Connection to Condenser Microphone type 4111 and Artificial Ear type 4109: These can be connected directly to the spectrometer, and all necessary voltages are supplied from the apparatus. It is possible to use a long cable between the microphone and spectrometer, on account of the built-in cathode follower tube in the microphone.

Connection to the Standing Wave Apparatus type 4002: With this apparatus connected it is possible to read absorption coefficients directly on the illuminated scale. The spectrometer has 3 scales covering the ranges 0—100 %, 0—70 % and 0—30 % absorption.

Connection to the Level Recorder type 2304: The spectrometer can be mechanically connected to the Level Recorder type 2304 by means of the Flexible Shaft type 3003 and the Speed Multiplier type 3004 which embodies a simple gearing, so that noise spectrograms can be automatically recorded on preprinted recording paper.

Tubes: 4 × 6AU6, 6X4, OA2, OB2.

Power Supply: 115 - 127 - 150 - 220 volts a. c. 50 - 60 c/s. About 30 watts.

Cabinet: Mahogany cabinet with handles and lid. Power cable in lid.

Dimensions: 51 (height) × 40 (width) × 20 (depth excl. dials) cms.
20 (height) × 16 (width) × 8 (depth excl. dials) ins.

Weight: 30 kgs or 66 lbs.

Level Recorder type 2334.

(the recording part of the Automatic Spectrum Recorder type 2311).

Frequency Range: From 20 to 200ooo c/s.

Zero Level: Adjustable from 3 to 12 mV. The instrument is supplied with a reference voltage of 10 mV.

Recording System: Patented moving-coil system.

Recording Speed: Variable in 9 steps from 1000 to 50 decibels per second with the 50 db potentiometer.

Damping of the Recording System: Feed back system giving max. restoring force.

Potentiometers: The instrument is delivered with one potentiometer. Potentiometers with 10, 25, 50 and 75 db ranges, two linear potentiometers from to to 110 mV and from 10 to 35 mV and a phon potentiometer from 35 to 110 phons are obtainable.

Accuracy: 75 db potentiometer: ± 1 db. 50 db potentiometer: ± 0.5 db, 25 db potentiometer: ± 0.3 db, 10 db potentiometer: ± 0.2 db, linear potentiometers: 2 % of full scale, phon potentiometer: ± 1 db.

Paper: 65 millimeters perforated and lined waxed paper for scratching with sapphire stylus or usual recording paper for ink writing. Effective recording width 50 millimeters. A sapphire stylus and an ink pen are supplied. The paper is illuminated in use.

Speed of Paper: 10 different speeds, 100—30—10—3—1—0.3—0.1—0.03—0.01—0.003 millimeters per second.

Polar Recording: To this recorder our attachment for polar recording can be directly connected. By means of this apparatus it is possible to make polar diagrams, and directional characteristics of loudspeakers and microphones, radar, aerials, and all radiation diagrams from mountings.

Drawing of Coordinate Lines: A Scratcher type 2360 provided with 11 sapphires for drawing 11 lines with intermediate spacing of 5 millimeters on unlinned waxed recording paper is obtainable.

Connection to other Instruments: Two rotating axles can be given the following revolutions per minute: 75—22.5—7.5—2.25—0.75—0.225—0.075—0.0225 and 0.0075. The axles rotate in opposite direction with respect to each other. To the rotating axles may furthermore be connected the Rotating Switch Type 4405.

Tubes: 4 × 6AU6 (EF94), 2 × 6AL5 (EB91), 2 × 6AQ5 (EL90), OA2, 6X4 (EZ90).

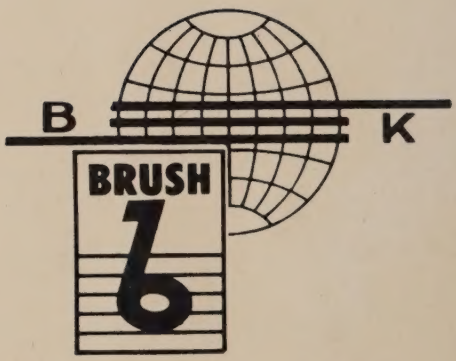
European Model.

Power Supply: 115 volts a. c. 60 c/s. 70 watts.

Cabinet: Mahogny cabinet with handles and lid. Power cable placed in the lid.

Dimensions: Cabinet 51 (length) × 31 (depth) × 23 height) centimeters
20 (length) % 12 (depth) × 9 (heigth) inches

Weight: 28 kg or 62 lbs.



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